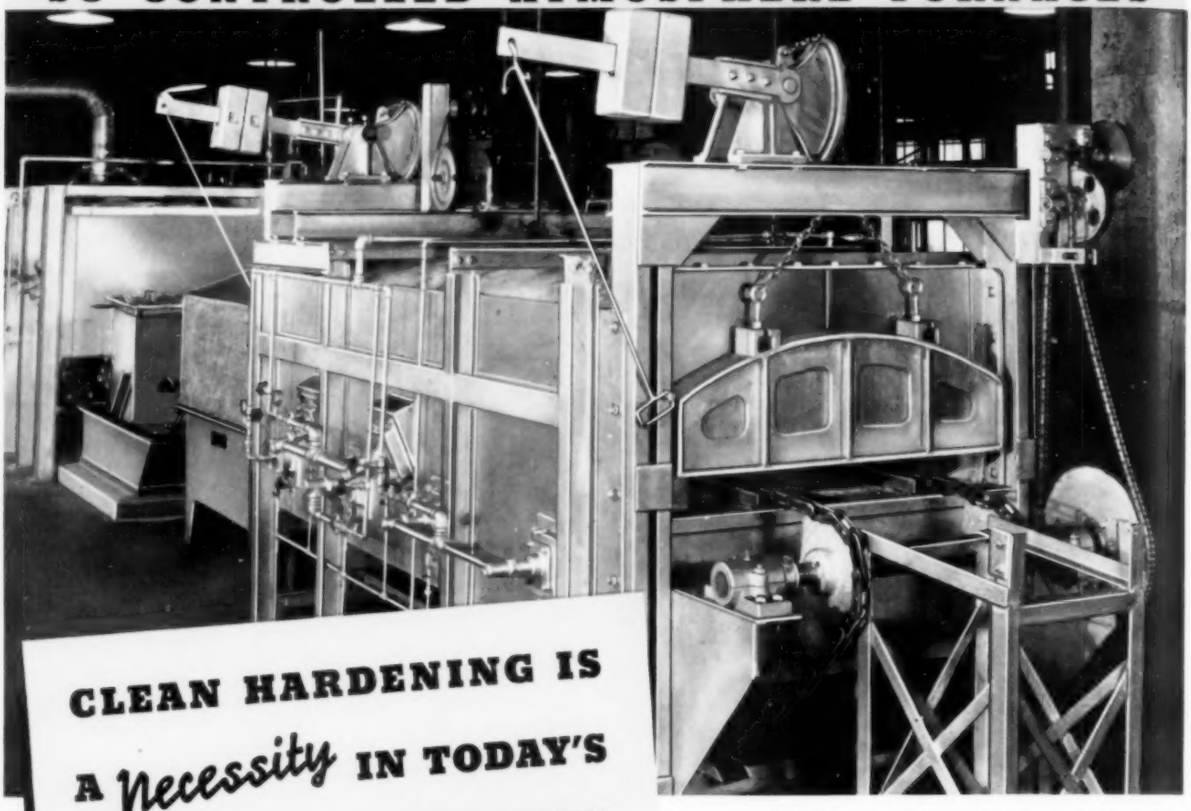
METAL PROGRESS

MARCH 1936

PAINTING OF BESSEMER PLANT BY A. H. GORSON, DONATED TO PENNSYLVANIA STATE COLLEGE BY ARTHUR G. McKEE

SC CONTROLLED ATMOSPHERE FURNACES



CLEAN HARDENING IS A *necessity* IN TODAY'S STRAIGHT LINE METHODS OF PRODUCTION

• *Discharge end of Drawing Furnace at terminal of hardening, quenching, washing, drawing production cycle.*

Industry's unceasing efforts to make good products better, cheaper, safer—its use of straight line production methods in accomplishing its purposes, has led to the development of new methods and equipment. Foremost in importance perhaps is steel treating—and such contributions to to steel treatment as SC Controlled Atmosphere Furnaces for clean hardening, drawing, bright annealing and EUTECTROL gas carburizing.

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Published by the American Society for Metals

Metal Progress

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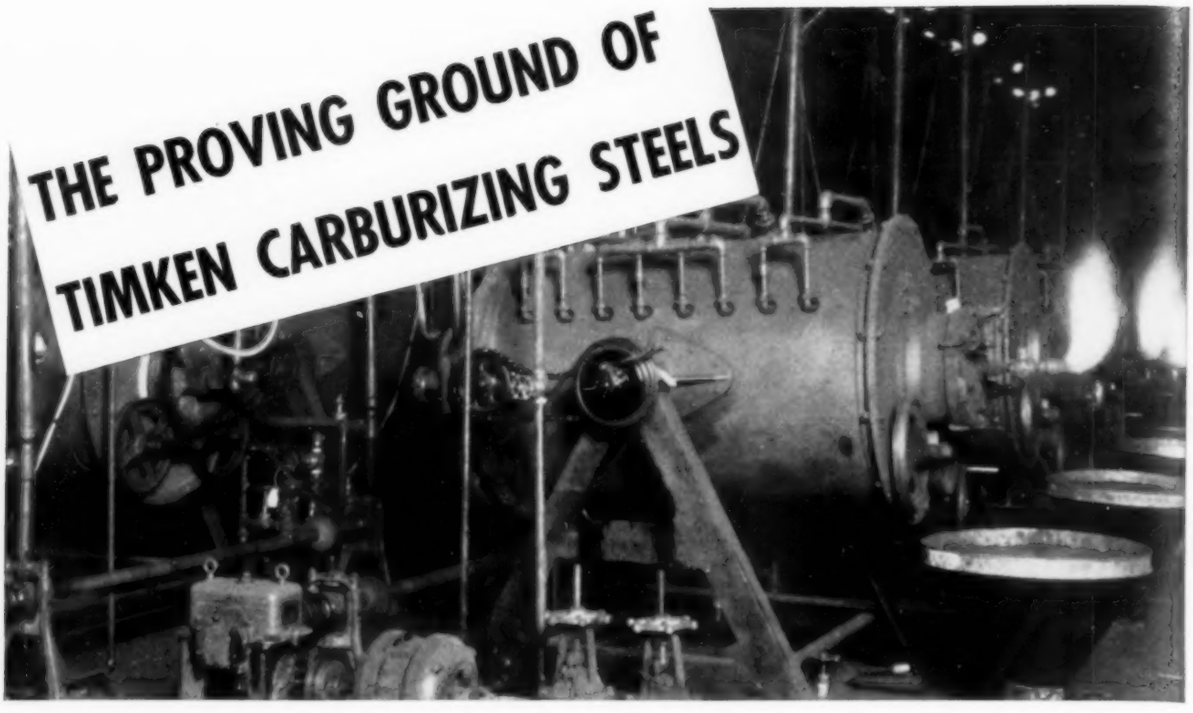
THE PROVING GROUND OF TIMKEN CARBURIZING STEELS



The consistently high and uniform performance of Timken carburizing steels is due in a large measure to many years of practical carburizing experience. With the tremendous fund of knowledge thus accumulated to draw upon, Timken metallurgists and steel makers are able to work with greater certainty as regards final results.

Furthermore, they have one of the largest and most efficient carburizing plants in the world at their disposal for research and testing.

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A View Ahead in the automotive industry

The Editor considers that four important trends can be predicted with fair certainty, having important bearing on passenger car design, and states them so that each reader can decide for himself whether they will affect the metallurgy of his particular product

IT WOULD BE PRESUMPTUOUS FOR AN OUTSIDER to predict immediate trends in specific features of automotive design, construction, or merchandising — the industry itself pays large salaries to astute executives to do this, and even they are not always correct in their appraisals of what the American public wants. It is more seemly, therefore, to call attention to a few expected trends, further extensions of past movements in associated lines of activities, and let the reader himself judge whether a ten-year projection of these movements, reasonably to be expected, will affect his own relationships with the automotive industry.

Four important trends are probable: (1) Fuel will increase in price; (2) roads will be further improved; (3) accident rates must be cut; and (4) greater comfort will be demanded. What does each of these trends imply to the specific problem of passenger automobile construction?

In the first place, more expensive fuel will require a much more efficient engine. It will be no answer to say "diesel engines," for when a large demand for fuel oil appears (and by "large" is meant more than can be had as a by-product of present refining methods) the price charged by refiners and distributors, and the tax burden charged by politicians, will quickly rise and wipe out the present differential between fuel oil and gasoline. Rather, it will involve a general redesign of engine and car to reduce the weight and improve the efficiency. Much of this will be a matter of engineering design rather than new materials or metallurgy, but nevertheless an air-cooled engine operating hot enough for maximum thermal efficiency, supercharged, running at such a high speed that rotary valves will be needed, and trimmed in weight down to say 3 lb. per horsepower — an engine built to approximately these specifications will require much new metallurgy or at least new refinements in old metallurgy.

The engine is not the only place where improvements in operating economy can be made. Car bodies (both automotive and railway car bodies) are now heavy boxes set on stiff underframes, the latter designed to carry practically all the normal stresses. In both automotive and railway car bodies, designs have already appeared wherein the body is structurally complete, and the present underframe is reduced to vestiges just large enough to act as the bottom chord of a box girder (which the entire body is). Such designs are so remarkably light for their strength and impact resistance that the improved mild steel sheet and strip will probably hold this present field against encroachment from high strength alloys, it having high enough elastic limit and ample ductility not only for service stresses but for easy fabrication.

Enthusiasts for good roads vision straight super-highways, multi-lane with streams of traf-

fic well separated; free from intersections at grades and avoiding cities and towns; heavy grades and sharp summits eliminated by long tunnels, bridges, and viaducts; adequately lighted for night driving; and with an anti-skid surface, rather than the one dictated by local industries. Such a program will require as much metal as did the railroad expansion in the West two generations ago, but in ways now well established (except perhaps new metals and new uses in a durable, non-skid road surface and in lights and their automatic control).

Such roads will invite higher speeds and longer journeys, and will introduce bodies which are adequately modeled to reduce wind drag, both from front and side. This is principally a matter of aesthetics and aerodynamic design and it is unlikely that any new metallurgy would be involved.

The third item mentioned above, greater safety, is thought by many to be principally a psychological problem. But to show how car design affects psychology, William B. Stout's experience with his new rear-engined car may be quoted. He said that the driver is no longer lulled into a false sense of security by thinking that the engine and its sturdy-looking hood will protect him in case of collision. When he sits right up in front with nothing much between him and approaching traffic except a windshield frame, he knows he is in a vulnerable spot and doesn't cut blind corners at nearly so high a speed. He also has a vastly improved field of view in all directions, and can see what to avoid. It is also believed that a car with low center of gravity and engine at rear will be much less liable to get out of control on a quick stop, for the inertia forces then act to equalize the pressures of fore and aft tires on the pavements, rather than as at present, tending to somersault the car around the heavily weighted front axle. Another safety item which is in the future, but involves metallurgy only in the producing industry, is the substitution of a transparent plastic or shatter-proof condensation product for glass in windows and windshield.

Lastly, a number of changes may be envisioned following the demand for more comfort and easier driving. Most of them, again, are matters of engineering design and while each will involve some metallurgical problems, they do not appear to foreshadow any revolutionary innovations. For the longer and faster journeys of the future, as well as the errands in and about town, wider, longer, and higher bodies will give more room for occupants and their movable comfortable chairs. A well-insulated body and air conditioning for summer will certainly follow adequate heating for winter. Soft springs, independently sprung wheels, big tires, all will make for a "floating" ride.

Eventually we will replace our present cumbrous gear shifting mechanism with an automatic torque converter, and the foot brake with an air compressor, so the driver will merely steer the car, and govern its speed with one or two buttons, "finger-tip control."

Cleaning of Stainless Steel Exposed to the Elements

AN ARTICLE IN LAST MONTH'S METAL PROGRESS quotes the eminent architect Ely Jacques Kahn to the effect that stainless steel at or near the curb line and exposed to close-up view should be protected with a clear varnish. This appears to be gilding the lily, for the varnish admittedly acquires a yellowish tone with age, is not very permanent, and certainly will harbor soot and dirt even more readily than a polished surface of stainless steel.

A dirt-shedding metal would be desirable, of course, but is probably beyond reasonable expectation. Even as hard, smooth and inert a substance as plate glass has to be washed periodically. It is to the credit of stainless steel window trim — as, for instance, at the Palmer House Cafe in Chicago — that it is washed only when the windows are washed, by the same men and in the same way, yet it stays bright and clear even in the windy, dirty Loop. On the other hand, laborious polishing of brass and bronze fronts at the main hotel entrance goes on nightly.

As everyone should know, stainless steel is not a cure-all, even on architectural trim, although it is far more stable and permanently lustrous than any of the other common metals and alloys used for such purposes. One would

have to go to gold leaf and the other truly noble metals for anything better, and even they would have to be cleaned. Soot, dirt, moisture, fly ash, and all the blown dirt of a big city will stick to the smoothest vertical surfaces — not much, of course, but still enough to dull the original bright luster.

The question at present is therefore not whether the metal must be cleaned, but how easily can it be washed and how frequently is it necessary to wash it if its pristine brilliance is to show forth. Even we automobile owners who have chromium plated or stainless steel hub caps, moldings or other ornaments realize that the car has to be washed all too frequently, and are glad enough when the metal shines forth bright again with no more effort than it takes to clean the lacquered body.

As a matter of fact, even 18-8 stainless steel will not wholly resist the city smudge if the conditions are such that sulphur-bearing ash can accumulate and remain in a crack or on a horizontal surface. In moist weather this will generate a little sulphuric acid, and, given enough time, corrosion and pitting will occur, together with a certain spread of dark stain. Even this can be avoided with reasonable care in design and erection, and a bath now and then in soap and water.

Gages for Enameler's Sheet

SHEET STEEL AS A FOUNDATION FOR ENAMELED sanitary ware, as described by Bennett Chapple in the February issue, would seem to offer some economies to the manufacturer and purchaser — although it must be remembered that the thin-walled castings which the sheet metal replaces can be made for a surprisingly low cost. Doubtless it will give good satisfaction in use, if (and it's a pretty big "if") if the sheet metal is thick enough and so formed that it will not flex or dent under normal mistreatment — such as, for instance, the stubby toe of a lusty five-year-old. If it does, any vitreous enamel will surely crack, and who wants cracked enamel in the best bathroom?

Undoubtedly the originators of this new type of ware are perfectly aware of these factors. The danger to them and to their development comes from the chiselers in the stamping and enamel-ware trade, who are always quick to shave gages of their steel sheet (as many a steel salesman can tell you).

You Are Missing Nothing

A POSTCARD BEARING THE FOLLOWING WAS RECENTLY received from Los Angeles, and signed by an assayer and chemist with D.Sc. attached to his name:

> ARE YOU MISSING SOMETHING?
>
> Through the technical press, you have been reading about the Spectrograph, which vaporizes the sample in an electric arc and photographs the spectrum. All the metals can be detected by this means in amounts as low as 0.001%.
>
> All the metals, including the rare earths and most of the other elements (seventy in all), are determined in a qualitative test, including a quantitative estimate to the nearest factor of ten, for $6.00.

There is something more than fishy in all this. In the first place, what is "the nearest factor of ten"? On some materials you could not crowd enough of the sample on an ordinary electrode to detect several of the elements in traces as low as 0.001%. For others some delicate preliminary concentration would be required. Likewise the worthy doctor of science who sends out this advertisement must like to work for nothing, for identification of the almost innumerable lines takes hours of work with equipment costing hundreds of dollars. One might just as well advertise to make a suit of clothes for $11.00 to the unknown specifications of a buyer, for it certainly would be worth far more than $6.00 to render a positive report on all the metals, including the rare earths. How much puzzling could be done for $6.00 on that suspicious line which might be 2840.02 for chromium or else 2839.99 for tin — maybe one-hundredth of a millimeter difference on the spectrum plate?

Perhaps the best way to end this "stop, look and listen" signal is to call attention to Thomas A. Wright's article on uses and limitations of spectrography in the January issue, and to quote (for the benefit of those who haven't sufficient time to read the complete article) his final words of caution:

"Reference has been made to the limitations of spectrography. Sanely developed through the cooperation of the analyst, the metallurgist and the physicist, more and more instruments will be installed. It is certainly true that one can, under certain limited and special conditions, get certain limited results which are badly needed and are valuable at that. Too much emphasis on low costs and speed, however, is placed by those enthusiasts and purchasing departments whose criterion as to service is price."

The Technical Man's part in sales promotion

Arguing from the thesis that steel and other alloys must now be adapted to their markets rather than vice versa, the author, who has directed many sales campaigns for new metals, shows how the technical man can fit himself into the modern picture of manufacturing metals and selling them at a profit

IN APPROACHING THE ASSIGNMENT OF DISCUSSING the technical man's part in sales promotion, I do it not as a technical man but as one having spent most of his life in advertising and sales promotion. Consequently the title might better be: "How a sales promotion man looks at metallurgical problems." However, as it *is* stated it is worthy of consideration, for the metal industry has entered a new era which will require some pretty radical changes. That goes for both salesmen and metallurgists.

In my opinion, the American steel industry is now confronted, for the first time in its history, with the necessity for selling its product. A long range view will show that, with some relatively brief intermissions, the steel salesmen have had one huge, new consuming market after another drop into their laps with no particular effort on their own part. The railroad development and the opening up of the West put steel on a tonnage basis in this country. Hardly was this completed when structural steel in buildings came along, followed by the automobile, with its tremendous contemporary developments in road building and the growth of the petroleum industry — both huge consumers of steel. Then came the War and the post-War building boom, all of which taxed the industry's capacity to produce. As a result, efficient production has always been the key to successful steel operations, and to this the mechanical engineer and metallurgist have contributed mightily. The technical man, in the good old days, could afford to ignore the fundamental problems of marketing. Then the merchandising philosophy, if any, was "We make steel; come and get it."

But things are different today. No one sees huge new markets just over the horizon. Railroad expansion is finished; building other than residential will not be resumed on a grand scale for a long time. The automotive industry is past its period of pyramid growth and probably will not exceed its record production of a few years ago. And what is the result? Efficient production, while still vastly important, is no longer the first consideration in steel. The major problem is sales. The day is past when steel companies will offer for sale only what they find it most convenient to produce. They have already begun to cater to the demands and even whims of the large buyer to a degree that would have been considered crazy ten years ago.

What this means to the technique of sales and to the metallurgists' relation thereto may best be expounded by citing some experiences already had with new alloys and new markets.

The commercial advent of stainless steels about ten

By Lawrence S. Hamaker
Vice-President and General Manager
Berger Mfg. Co., Canton, Ohio
Formerly Sales Promotion Manager
Republic Steel Corp.

Photo by H. W. Fortey for Warner & Swasey Co.

Once Upon a Time Pig Iron Was Just Pig Iron — But No More!

years ago was a challenge to the steel industry from a merchandising standpoint. Stainless steel has literally thousands of uses. You could almost shut your eyes, jab a pin in the Department of Commerce list of industries and come up with a market for stainless. The problem was to determine which markets warranted intensive cultivation, and since many of them had never before been considered as important outlets for steel, we had what amounted to a pioneering job on our hands.

Some markets, such as the preserving, canning and restaurant industries were obvious; the makers of dairy machinery and the oil refiners quickly fell into line. It began to be used almost voluntarily for building decoration and automotive trim. None of these involved profound market studies, though a great deal of laboratory work was done on the product itself. Our real work began when we introduced stainless into industries that didn't know they needed it.

An interesting case in point is the tobacco industry. We had been receiving a number of orders from tobacco companies which seemed to indicate a market, but this industry is tremendously secretive about its processes and it was impossible for our salesmen to get into the plants or to secure any information as to the use being made of our product. We were told that it was necessary to sell the company's headquarters in New York, but in New York we were told that they were buying stainless as a matter of pride — for appearance and trim, and that they had no corrosion problems. However, on getting into the plants, which we finally succeeded in doing, we found that they had a genuine corrosion problem due to the action of complex organic acids arising during the course of the tobacco handling and working processes.

Briefly, our survey showed us immediately that the industry had six divisions — raw tobacco, smoking tobacco, cigars, chewing tobacco,

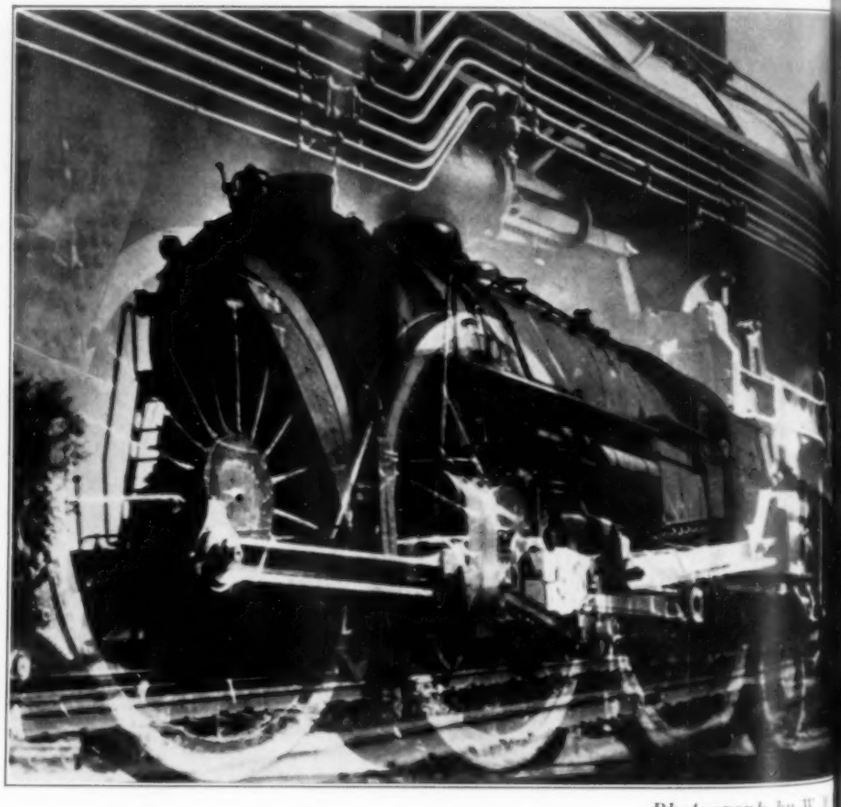
snuff and cigarettes, of which only the cigarette people had money to spend for equipment. It was immediately apparent also that this market could be reached only through the services of our metallurgical staff, as the corrosion problems, being unique, required individual study. The market volume, due to the concentration of this industry in North Carolina, Virginia, and Kentucky was easy to estimate at between one and two million dollars. No advertising was recommended because the industry has no good trade publication dealing with the production end (due to the secrecy surrounding production processes). For the same reason mailing matter featuring performance data would be fatal, as this would divulge "secrets." As a result we are selling this industry by direct contact, which fortunately is easy due to its convenient geographical concentration.

One of the most successful surveys had to do with the textile industry.

We in the Republic Steel Corp. did no advertising to the textile industry until we had something specific to advertise. As a result of our survey, two metallurgists were assigned to a large textile institute in the East for a period of many months, where, under a special arrangement, they were able to avail themselves of a huge amount of test data.

As a result these metallurgical salesmen were equipped to sell the industry on an intelligent, effective basis. They did not go into a plant, as competitive salesmen were doing, and talk about the metallurgy or general corrosion resistance of stainless. They were equipped with a very convincing sales kit showing swatches of material which had been dyed with the same color in tanks of porcelain, wood, a non-ferrous metal, and stainless. The difference in shade of color is very marked, although the same dye was used in each case. This is such a familiar bugaboo to the textile man that he gives it his full attention and when he is shown that the samples dyed in a stainless tank and in a porcelain vat are identical, the sale is practically made! Our progress with the entire industry has been very rapid because our men know exactly what they are talking about, which gives them a decided edge on competitors who must deal in generalities.

In Chicago we made a survey of the meat packing industry which I will not describe in detail except to say that once our men knew exactly where stainless steel should be used and why, where competitive materials had failed in service and where ordinary materials were plenty good enough, they succeeded in increasing our stainless sales to the meat-packers 300%. All this in the first year. The technical men who secured the basic information in these surveys are not doing the actual selling. The knowledge gained



Photograph by W. I

The Railroads Were Once Steel's Principal Customer in Point of Tonnage; Those Days Have Gone Forever

has been put in a form that any salesman can handle and any prospect can understand. (More will be said later about the necessity of talking to your audience in terms it will understand.)

Will It Sell at a Profit?

The above will indicate some of the ways that technical men can vitally affect sales policies even after they have developed a new steel or alloy. Let me, therefore, return to my original thought that the metallurgical industry must do this type of selling in the future. (I talk "steel" because that is my industry, but I rather feel that the same applies to aluminum, copper, zinc, and magnesium.) Fortunately the metallurgists have developed many new alloys with corrosion resistance, high strength, or special mechanical or electrical properties, that provide the real merchandising opportunity. Also most of the older lines of standardized production (sheet steel, for instance) have been so refined and perfected by wide-awake technical men that they are vastly improved either for fabrication or use.

The important thing for the manufacturer to know in these circumstances is not "Can I make it?" but "Can I sell it at a profit?" A few of the most obvious questions to be asked are these: What is the potential market for the new product? How much am I justified in spending in development? Is it a one-industry product? How much educational work would be required to sell it? What kind of a sales set-up shall I need? And there are many others. While it is being done every day, I see no excuse for any manufacturer plunging into the production of a new product without definite information as to its market possibilities.

A typical example of a company that leaped before it looked is a well-known manufacturer of valves, more than a half-century old, who was offered a patented valve for the oil field. Because the unit of sale was high, about $2,000, and because the product was one the company could make easily, a deal was closed agreeing to pay the inventor $50,000 a year royalty, regardless of the number of valves sold per year. After a year or so of disappointing sales, the company made a careful survey of the market. (Yes, it did!) It was found that if this company got all the business for this type of valve in the United States, it could not get enough to pay the inventor's royalty. Even if it secured *all* the foreign business for this type of valve it would still be back of the eight ball! At the end of the second year their agreement was canceled and the product dropped at a loss of $200,000.

As an example in the other direction I might point out the experience of a large copper and brass company which fortunately is market-wise. It was offered a new type of electric heater, which promised a substantial consumption of copper and brass. Tests proved the heater to have considerably better heating capacity than existing types with only slightly higher current consumption. Cost estimates showed that the heater could be produced to sell at a list price of $40. Instead of rushing into production this company made a careful investigation of the heater market. The results were interesting. It found that there was not a profitable market for the heater despite its merit. The $40 price was too high. There were a number of good-enough heaters on the market selling for about half the price. It found also that two other manufacturers were about to bring out improved heaters which would do practically everything that the heater under consideration would do and would sell for around $20. This concern did not add that heater to the line. Many another company is money in pocket because of a new product that it did not bring out!

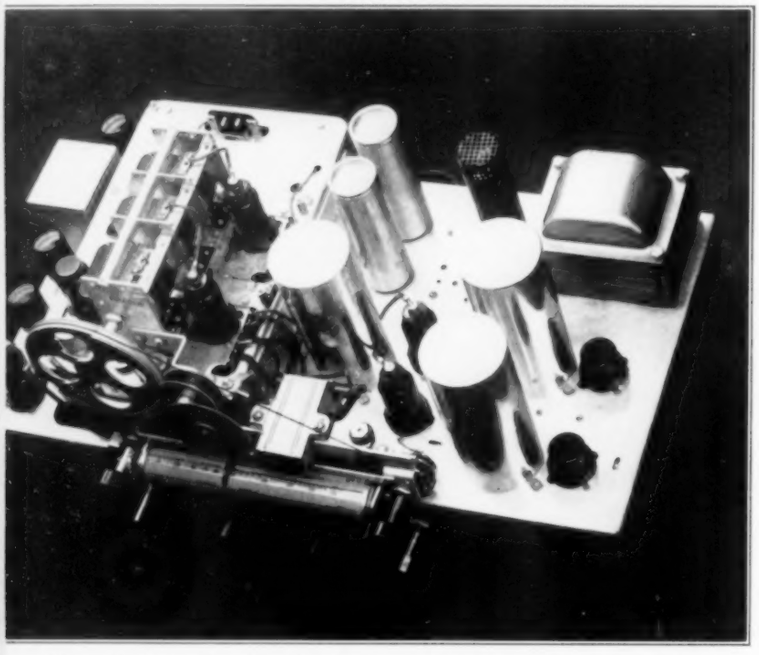
There are many other examples I could give, but they all add up the same answer, which is this: The technical man in developing or improving his product should have the ultimate consumer in mind, as well as the production facilities of his plant. He should become a commercializer. He should be prepared to translate his knowledge into terms which the sales and advertising departments can use and understand and if these departments seem to employ some of the methods of the late P. T. Barnum he should realize that they do so because people insist on behaving like human beings and such methods are the easiest way to get the story over.

Technical Men and People

I know from some years of contact with technical men in the steel business that the behavior of society is frequently puzzling and sometimes irritating to a man accustomed to logical decisions, to reasoning from cause to effect, trained to conduct his affairs on rational principles, known facts and measured results. *People*, on the other hand, are intolerant of facts and act by prejudice, tradition and mass impulse. Yet the gropings of society and the precision of the technical man have the same objective. The

metallurgist who creates a new, safer metal has the same goal as the social reformer who maintains that the world owes every man a living. Both are intent on reaching the goal of certainty and security.

From my position as an outsider, I think I see what is wrong with the thinking of many technical men in their dealings with people at large. I am convinced that the most important factor in business is not the concrete problems arising from day to day, but the human contact which is



New Markets for All Metals Come From Wholly New Industries. In such a thing as a GE radio chassis with all-metal tubes the requirements are highly specialized — "tailor-made" metal is the rule

inseparable from every business activity (with the possible exception of advanced scientific research). Markets are *people*, business organizations are *people*, and regardless of their respective stations in life they all have the same general reactions.

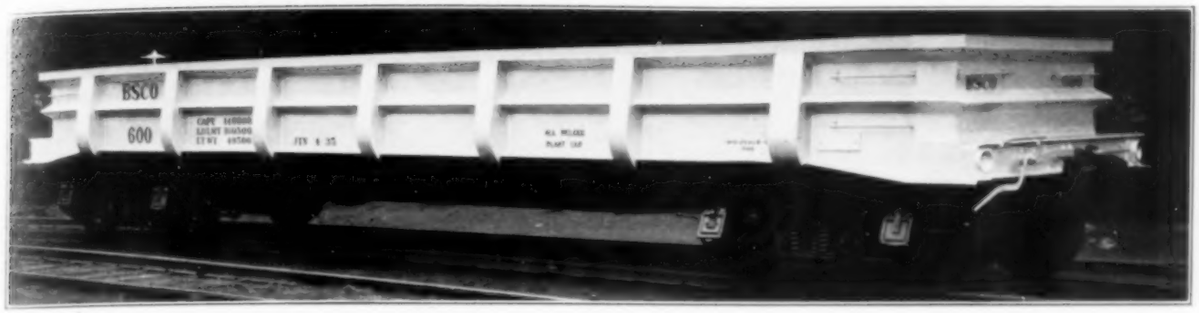
The educated man, the technically trained specialist, has by the very fact of his training, lost something of the common touch. People, by and large, are almost unbelievable. At the time of the War, when intelligence tests were applied to drafted men, there was great amazement over the fact that the average intelligence quotient was that of a 14-year-old school boy. Advertising men had known that for years and it is something that most technical men, if they are interested in having their knowledge achieve the widest commercial use, would do well to keep in mind.

In other words, do not assume that people generally look at your problem from your viewpoint or from your perspective. One more illustration of this fallacy and I'm through.

We have all been talking and thinking (and some of us doing something) about steel in small houses — even pre-fabricated houses. You will remember a group of really modern houses at the Chicago Fair. More than a million people went through these houses and were asked to fill out a brief questionnaire listing the three things that impressed them most. More than 200,000 of them did so. Bear in mind that these houses were of steel and glass and were about as radical a departure from conventional housing as could be imagined. In spite of all the research and effort spent in developing new types of construction, in spite of scientific achievements in insulation and the adaptation of materials never used before in housing, first by a wide margin on the list of impressions was, believe it or not, twin beds! The general public had never seen them! Number two was Venetian blinds, which have been used since the time of Julius Caesar. Number three was, naturally enough, air conditioning, because Chicago was hot and the houses were cool. (I imagine they would have got a similar reaction from serving hot dogs if most of the people were hungry.) Nothing in the results about flat roofs or steel or glass or new type heating equipment requiring no basement.

And this was a perfect cross-section of the American public. I cite this merely to point out how very easy it is to shoot over the heads of ordinary people.

So, in my opinion, the technical man must not only learn to interpret his knowledge in terms of the non-technical mind, but he must get a fairly accurate picture of the type of people who will have to understand his message and the way their minds work. When this is done he will go far. When it is not done he will probably be disillusioned. The history of the steel business and of every other basic industry is replete with examples of discoveries of fundamental importance that lay idle for years until someone with the common touch came along to make them commercially feasible — usually reaping all the rewards and most of the glory in the process.



Welded Underframes for freight cars

Bethlehem Steel Co. has constructed a number of all-welded gondola cars for plant use. These cars are stiffer and lighter than conventional riveted construction and have given such excellent service that Lehigh Valley Railroad has bought 135 70-ton gondola cars of mill type with all-welded underframe

THROUGH THE INTELLIGENT USE OF MODERN WELDing sets and corollary equipment, Bethlehem Steel Co. has improved the art of railway car construction so as to embody the many advantages welded fabrication offers. An appreciable amount of over-all dead weight is saved without sacrificing rigidity of structure, or radically altering the basic design except for the underframe — which is of all-welded construction.

Now that this type of welded fabrication has been established as good practice — by reason of the fact that it has been incorporated in the design of 135 70-ton gondolas purchased by the Lehigh Valley Railroad Co., and in a type of car designed for heavy duty in steel plants — it may be of interest to describe the methods employed to develop the all-welded underframe.

To determine its practicability considerable development work was necessary. The greater portion of this preliminary work was carried on at the Bethlehem plant of the steel company, rather than at the Cambria plant in Johnstown, Pa., where all activities of the parent company relating to the construction of freight cars are centered. This development work included the actual fabrication by welding of underframe structures and complete pilot cars for test purposes. One of the latter is shown above. Its pleasing lines are at once suggestive of great strength and durability.

Various tests were made on these finished structures. When loaded to capacity, accurate measurements showed less deflection for the welded type of underframe than for the conventional riveted type of same capacity, size and intended duty. The strength of the welds was found to equal that of the parent metal, which was mild steel conforming to car-builders' specifications. Pilot cars have been in continuous and heavy service in plants of the Bethlehem Steel Co. over periods ranging from one to two and one-half years, and

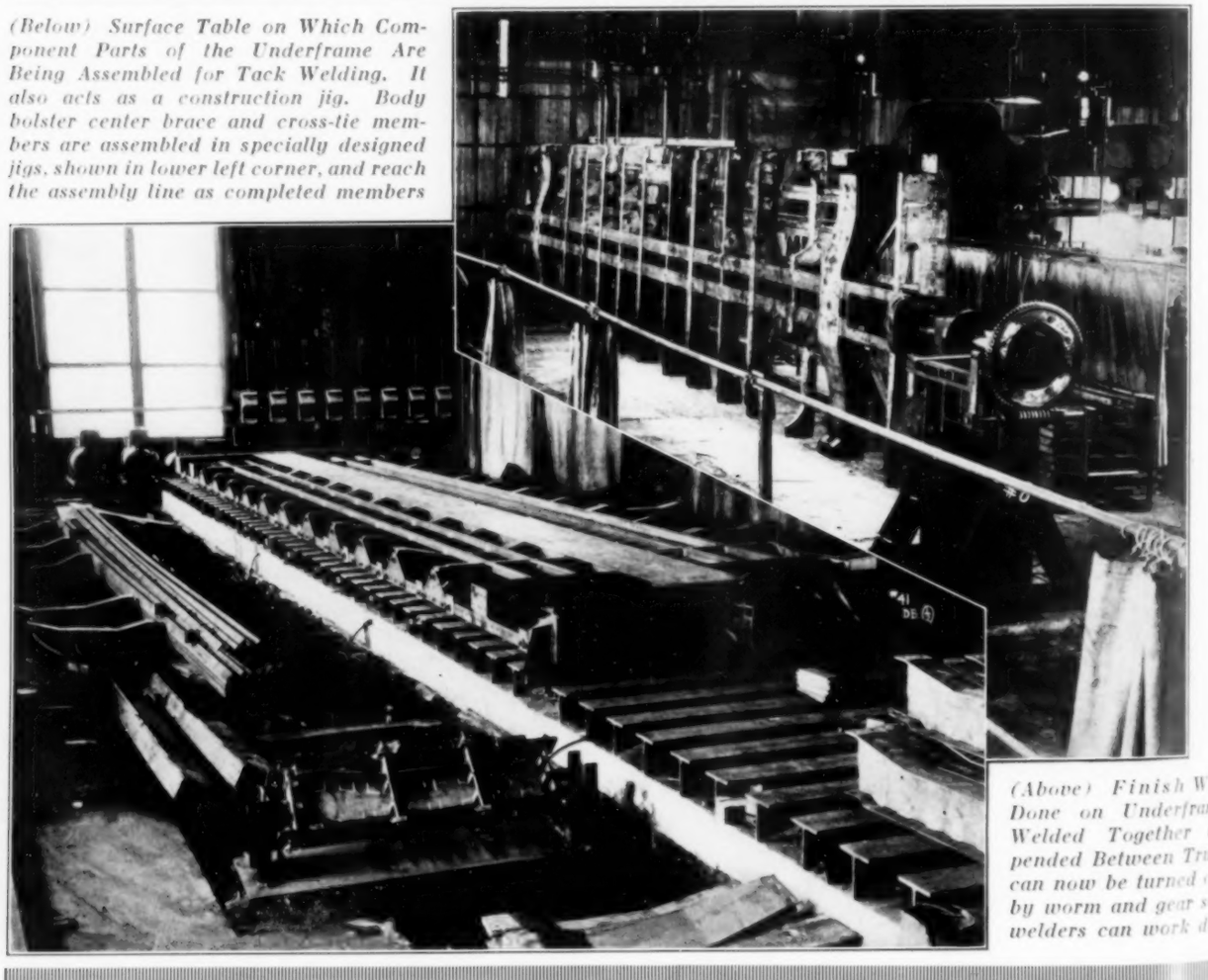
By Scott D. Baumer
Assistant Superintendent
Car Shops, Cambria Plant
Bethlehem Steel Co.

offer mute but convincing evidence of the practicability of welded fabrication for structures which must resist heavy shocks.

This groundwork of experiment was necessary because it insured a certain familiarity with every component part of the underframe and for the completely welded pilot cars. It also developed efficient methods for handling the parts when operations were placed on a mass production basis. It ironed out seeming difficulties encountered in the welding operations and was chiefly responsible for the sequence of operations best suited to the new method of making the joints.

There was a need for additional facilities at the Cambria car building plant so that the welding activities would dovetail into the established production scheme of car construction. To satisfy the requirements for a minimum production schedule, additional space was made available in a building adjoining the car shops. Ample room was also provided for a school of advanced welding technique. Experienced welders were put in training and as fast as they qualified on flat, vertical and overhead welding with the bare electrode, they were trained in the making of approved butt welds with heavily coated electrodes. Minimum tensile strengths of the latter welds were held to 60,000 psi. and elongations to 20% in 2 in. After passing these requirements they were assigned to work on the all-welded plant cars, similar to the one shown in the illustration at the head of this article.

The corollary equipment installed to expedite the welded fabrication of underframes consisted of 29 single-operator welding sets; automatic flame-cutting units, pantograph-type; necessary jigs for the fabrication of the body bol-



(Below) Surface Table on Which Component Parts of the Underframe Are Being Assembled for Tack Welding. It also acts as a construction jig. Body bolster center brace and cross-tie members are assembled in specially designed jigs, shown in lower left corner, and reach the assembly line as completed members

(Above) Finish Welding Done on Underframe Welded Together and Suspended Between Trunnions can now be turned on its by worm and gear so that welders can work down

ster center brace, crossties and other units; six especially designed trunions in which to suspend and turn the assembled underframe so that all finish welding could be done in a horizontal or down-hand position; a surface table 210 ft. long for a set-up bed, made up of 8-in. I-beams anchored parallel in a concrete foundation.

After a series of operations on the component parts of the underframe structure have taken place on the set-up bed (or in smaller jigs in the case of crossties, so they can be applied as one completed piece) the assembled underframe is completely welded, taken to the erection shop where brake rod supports are added, and the final assembly of the complete car takes place. An analysis of these operations more readily indicates the type of work involved.

Analysis of Operations

The first operation consists of setting up the center sill, coupler-striker castings, separators and body-bolster braces for the required type and size of car on the surface table, which in itself is a type of jig. Here these parts are fitted and tack welded in place so that the assembly can be moved by crane to the next section of the table where all horizontal surface welds are completed. From this bay the assembly is moved to the next position for cambering and cover welding, and after these parts are skip welded or tack welded the assembly is moved to its next position for fitting the necessary crossties, bolsters, and end sills to the center sill, adding the floor supports and tack welding them in place.

All these positions are on the 210-ft. set-up bed and up to this point all welding operations are confined to a horizontal plane parallel to its surface. To permit all finish welding operations to be carried on in a down-hand position, the underframe assembly is next suspended between trunions whose shafts are extended into the openings of the coupler-striker castings. In these trunions the section is revolved by a hand-powered worm drive to bring it to any desired position for the convenience of the workmen. When the assembly is finally removed from the trunions it is a completely welded underframe; the only thing that remains to be added is brake rod supports and other minor accessories as a complete freight car is being assembled in the erection shop.

The cars referred to are mill-type gondolas of A.A.R. Class GM, measuring inside: Length 50

(Continued on page 88)

Bronze Electrodeposits

by C. Bechard

Condensed from Journal of Electrodepositors' Technical Society

IN THE ELECTRODEPOSITION OF TWO OR MORE METALS in the form of an alloy, if it is desired to work a bath over a long period of time and to obtain an alloy of constant composition, it is essential to regulate the composition of the electrolyte itself within close limits.

In the case of brass, anodes of the two metals copper and zinc can be used to maintain the solution, because the anodic dissolution of the two in the cyanide bath is perfect and the proportions of the two metals for rejuvenating the solution can easily be controlled by suitable choice of the ratio of the exposed surfaces of copper and zinc. In this manner the mean composition of the electrolyte can be maintained constant. The same can be done in the case of bronze (copper and tin), if conditions are under close control.

Bair and Macnaughtan have already shown that excellent bronze deposits up to 0.030 in. thick can be had from alkaline solution of sodium cuprocyanide and sodium stannate. By varying the relative concentrations of copper and tin in the solution bronzes of different compositions were produced, and the metal concentration of the solution satisfactorily maintained by the use of annealed cast bronze anodes. These solutions have great throwing power and the deposit is quite dense, no pores being found in deposits 0.0002 in. thick. Since a nickel deposit must be three or four times as thick to be free from pores, the bronze deposit should prove to be a superior undercoating for a chromium plate.

The studies forming the basis of this later work were undertaken to evaluate the possibilities of copper and tin anodes rather than bronze anodes. They indicated that the acid bath, made of ammonium-tin and ammonium-copper oxalates and using anodes of tin and copper, is unstable and difficult to keep reasonably constant in composition. Very much better results were had from alkaline baths, as follows:

Electrolytes were prepared by mixtures of two solutions of the following composition:

Solution A. 200 g. of crystallized potassium cuprocyanide per liter. *(Continued on page 94)*

An Appreciation of William Adolf Irvin

Photo by Blank & Stoller

President, United States Steel Corporation

THE ACTUAL QUARTERS COMPRISING THE OFFICE OF the president of the United States Steel Corp. overlook old Trinity Church and its famous churchyard, from the 18th floor of 71 Broadway, New York City. It is a far distance from these dignified though modest rooms to the blast furnaces, the 200-ton ladles of molten steel, and the gigantic mills of the manufacturing subsidiaries, even though important aspects of their operations are controlled from this office.

A visitor, whose business gains him admission, is nevertheless well aware that he is in the presence of a steel man. No polished lengths of railroad rails, no cabinets of bolts or nails, no bird's-eye views of 1000-acre plants, no photographs of roaring bessemer converters are needed to proclaim the office of a steel executive. William A. Irvin looks, talks, and acts as an iron-master should. His handclasp is brief, crushing and warm; his speech is smooth, correct, unadorned, but rich in idiom; his voice is characteristically deep, resonant and vibrant, and well it should be, considering that it comes from a chest like an old-time "pot-puller's" in a crucible shop.

President Irvin comes to his office at about nine each morning from his home in Westchester County, usually finishing the trip by subway. Thereafter his activity is prodigious; those who know him suggest that his early training as a railroad telegrapher developed an adequate facility for making his wishes known — quickly, and over a wide territory! Perhaps two traits afford the clearest insight into the impression he creates upon other people; first is his fine sense of humor which is seconded and exceeded only by his sense of fairness at work and at play.

By way of biographical data, he was born William Adolf Dec. 7, 1873, at Indiana, Pa., where his father, of Scotch descent, was a successful contractor. His mother, the former Sophia Bergman, was of German ancestry. After finishing the public school he entered the State Normal School, but soon started working for the Pennsylvania Railroad Co. in 1888 as telegraph operator and clerk. By the time he was 22 years of age he had found his life work in the steel business, starting rather low on the ladder of success as shipping clerk for P. H. Laufmann, Ltd., of Apollo, Pa., manufacturers of sheet and tin plate.

Five years later, when the American Sheet Steel Co. took over the Apollo plant in 1900, Irvin had already risen to be superintendent of the plant, and was then transferred to the general offices in New York City. After the American Sheet and Tin Plate Co. acquired his company by merger in 1904, he was moved to Pittsburgh as assistant to the vice-president in charge of operations. For 20 years he effectively handled those innumerable details and their coordination, which, in the aggregate, constitute the running of a steel business. In 1924 he became vice-president in charge of plant operations of the American Sheet and Tin Plate Co., with executive offices still in Pittsburgh. In September, 1931, however, he was elected vice-president of the United States Steel Corp., and six months later became president, succeeding James A. Farrell. Mr. Irvin is thus of the younger school that knew and worked with such elders as George G. McMurtrie, John Topping, Wm. T. Graham, E. W. Pargny, S. A. Davis, Homer D. Williams, W. G. Clyde, Elbert H. Gary, James A. Farrell, Eugene J. Buffington, Wm. P. Palmer, Wm. B. Schiller, Taylor Allder-

dice — executives who gathered a group of men and manufacturing plants into the powerful business organization now known as U.S. Steel.

Mr. Irvin married Luella Cunningham of his home town and to the couple five children were born but the mother of these children did not live to share more than the beginning of her husband's career. Mr. Irvin married a second time in 1910, the present Mrs. Irvin being the former Mrs. Gertrude Whitman Gifford.

For recreation "W.A." rides horses and plays good golf — his opponents now usually concede him putts up to 30 ft., and he is a member of the Hole-in-One Club. He is pretty bad news to wild ducks during certain seasons, and in others he teaches safety rules to bass, trout, pickerel and tarpon. He has a very soft spot in his heart for English setters, horses and trees. During his long residence in Pittsburgh, Mr. Irvin was a familiar figure at the Duquesne Club, and as president of the Pittsburgh Field Club was very active in building up its present beautiful and extensive property. Although perforce somewhat inactive, he maintains membership in many technical societies including the Engineers' Society of Western Pennsylvania and the Society of Automotive Engineers.

As an executive William A. Irvin is, first and foremost, interested in men. In his outlook he typifies the forward-looking, intensely human, modern administrator of so-called big business. In an address before the American Society for Metals last year he said, "It almost goes without saying that the productive processes of industry are still primarily dependent upon brains, regardless of how well our plants are equipped with mechanical devices. Men construct, guide, and operate machines; they uncover natural laws, originate ideas, devise methods, and make decisions; without their direction and control the application of horsepower and other physical agencies would be futile." It is a safe assumption that he said what he meant and meant what he said.

Probably any one of his close friends would be moved to say a few sentimentally complimentary things about his personality and generous traits; equally probably they might restrain themselves, knowing how "W.A.," habitually shunning the limelight, would deprecate any such attribution of unusual qualities.

By Augustus B. Kinzel
Chief Metallurgist
Union Carbide & Carbon Research
Laboratories . . . New York

IN ORDER TO PRODUCE LIGHTER STRUCTURES FULLY as strong as heavier ones previously were, or stronger structures no heavier than before, the metallurgist must be able to produce steel of high strength which can be readily manufactured in large quantities with uniform results. The solution of his problem is found in alloy steels which, in the as-rolled condition, will have the desired properties embraced in the broad term "ductility." Many alloy steels are suitable, but those made from raw materials most readily available and requiring the minimum of production effort are naturally to be preferred. Chromium, manganese and silicon have definite advantages as alloying elements in the production of such steels.

Considerable is known of the effects of chromium and manganese on the critical points of steel with moderate carbon content, and of chromium on carbon-free iron. Small amounts of chromium tend to depress the critical temperature by slowing up the transformation reaction rates, whereas manganese actually depresses the equilibrium temperature of transformation down to a much lower point. When chromium is in sufficient amount (for instance, 12.5% in a carbon-free iron) the gamma phase is completely eliminated at all temperatures, because chromium is a ferrite-forming element. Ferrite makes for forgeability.

Manganese, however, is an austenite-forming

Chromium & Manganese

in structural and stainless

The author of this paper traveled to Moscow, U. S. S. R. in January to present it before the Society for Science and Culture. It contains a logical explanation of the interrelation between chromium, manganese and silicon in the low alloy steels and also in high alloy, austenitic-ferritic stainless steels having interesting properties competitive with the well known 18-8

element. When enough manganese is present in steels that contain no other alloy, austenite may be retained to a large extent even on slow cooling. Austenite is more easily cold worked. Both chromium and manganese form carbides readily, although the chromium carbide is much more stable. Both chromium and manganese are soluble in ferrite and are partially dissolved in it when present in excess of the amount necessary to satisfy the carbide equilibrium. (This statement holds only when steel is so treated that very little austenite is present.)

Thus, the effects of various combinations of chromium and manganese when dissolved in the ferrite lattice are most important, being secondary only to their effect on the air hardening properties. To have optimum physical properties in the as-rolled condition, a chromium-manganese steel should therefore maintain the proper amount of carbide suitably distributed for strengthening the aggregate, and of chromium and manganese in solid solution; furthermore, the analysis should be such that the undesirable effects of excess air hardening are absent.

Low Chromium Carbon Steels

In order to illustrate in more detail, three different types of steel will be described: First, low chromium carbon steels; second, medium manganese steels with and without chromium; third, various types of chromium-manganese steels, together with the added effects of silicon.

The first example, a 1% chromium steel with 0.10% carbon as normalized, has a microstructure consisting of ferrite with appreciable chromium in solution, pearlite made up of similar ferrite and carbide, and chromium carbide or mixed iron-chromium carbide particles rejected from the previous gamma phase or precipitated from the alpha phase in the form of minute spheroids. The amount of chromium in the solution is sufficient to strengthen the ferrite without embrittling it. The amounts of pearlite and carbide serve to key the entire structure, but not so rigidly as to produce low ductility. The average grain size of the steel is sufficiently small so that additional strengthening is obtained by end interference of slip. This steel therefore has very desirable physical properties, for it is strong and yet reasonably ductile.

If, however, the carbon is increased appreciably, martensite or troostite replaces the pearlite and the amount of spheroidal carbides present increasingly keys the lattice. The result is to produce a notable lowering of the ductility with only a moderate increase in strength. If the chromium content is increased markedly without increasing the carbon, the stiffening of the lattice by the solid solution effect also causes a decrease in the ductility. If, however, the carbon and chromium are simultaneously increased

in proper proportions, so that the distribution of the carbide is properly maintained and the chromium in solid solution is held at a proper level, the resulting steel on air cooling will have increased strength, and the ductility will not be disproportionately lower.

In these low chromium low carbon steels, manganese is usually very low. In practice it is common to specify a maximum of 0.50% manganese for chromium steels to be used as rolled. The minor effect of these small amounts of manganese does not qualitatively change the physical properties. If, however, the manganese is increased above 0.50% in the 1% chromium steels, there is a tendency toward formations of martensite and of manganese carbide. Furthermore, the amount of chromium and manganese in solid solution is markedly increased and the distribution of the carbide altered, the cause probably being the increased spread between Ac_1 and Ac_3. The net result is that the steel, while having somewhat increased tensile strength, has a disproportionately lower ductility.

Medium Manganese Steels

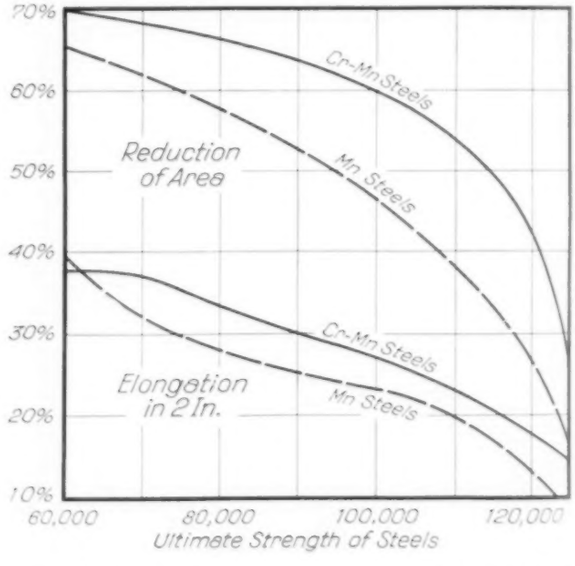
The second example is the normalized medium manganese steels with 1.5% manganese and 0.30% carbon. In such steels, the pearlite and carbide distribution as well as the solid solution effect of the manganese, results in a relatively high tensile strength — for example 85,000 psi. The ductility remains sufficient for most engineering purposes, although it is not quite as good proportionately as that of the chromium steels. Such material, however, undoubtedly has engineering value.

Increase in the carbon content very quickly changes the carbide distribution and lowers the ductility. This effect is probably attributable to segregation of manganese in the austenite-forming areas of the two-phase structure that exists in the range between the lower and upper critical points on heating. The same effect, probably due to the same cause, results from a further increase of manganese. For example, a 2% manganese steel with 0.40% carbon will probably be quite strong but seriously low in ductility.

The addition of chromium to the medium manganese steels improves this condition, apparently by decreasing both the carbon available for combination with the manganese and the tendency to micro-segregation, and by maintaining the proper distribution of pearlite and carbide after air cooling. Thus, chromium in moderate amounts is markedly beneficial to the medium manganese steels. However, if the chromium content is increased to a point appreciably above 0.50%, we arrive at the same undesirable condition as when we increase the manganese in the plain chromium steel.

(Before proceeding, it might be well to refer again to the micro-segregation mentioned above. Unfortunately, we have not been able to obtain direct proof of this in manganese steels, although the distribution of retained austenite on rapid quenching indicates very strongly that the hypothesis is correct.)

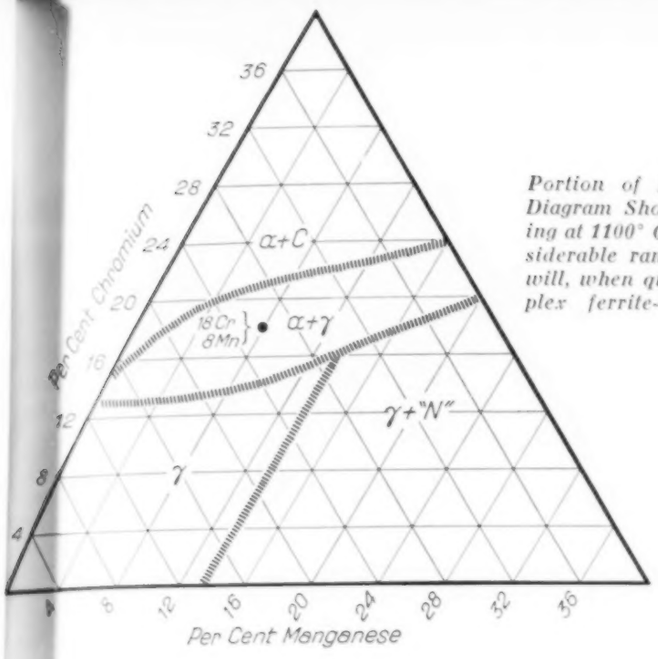
All of the above brings us to the question of how properly to proportion chromium and manganese in a steel of moderate section to be used in the as-rolled state, or how to arrive at a "balanced composition." The term "balanced composition" is simply a convenient way of saying



Ductility of Low Chromium, Medium Manganese Steels Drops So Rapidly When Heat Treated or Alloyed to Ultimate Strengths Beyond 100,000 Psi. that Steels of This Type Are Known as "Unbalanced Compositions"

"that composition or range of composition that results in optimum relationships between strength and ductility with a given type of heat treatment and section in a given tensile range."

In the first figure, the reduction of area and elongation are plotted as a function of the ultimate strength of normalized chromium-manganese steels in 1-in. section. The ultimate strengths were controlled largely by modifying the carbon content, but the manganese steel in each group has approximately the same carbon



Portion of Fe-Cr-Mn Tri-Axial Diagram Showing Phases Existing at 1100° C. (2000° F.). A considerable range of compositions will, when quenched, have a duplex ferrite-austenite structure

content as the corresponding manganese-chromium steel. Note the "knee" in the curve for reduction of area, starting at approximately 100,000 psi. This leads to the statement that the ductility of normalized, 1-in. round, chromium-manganese steels of a given tensile strength is relatively high up to 100,000 psi., and that beyond this point the decrease in ductility is so great as to be considered disproportionate, and the latter steels represent "unbalanced compositions at higher strength."

Chromium-Manganese Steels

There are many desirable compositions of chromium-manganese steels for high properties. For steel sections up to 1¼ in., if the strength range is 70,000 to 95,000 psi. and carbon from 0.10 to 0.20%, the optimum ductility-strength relationship in the normalized state is obtained with 1.25% Mn and 0.5% Cr. This represents a balanced composition. Likewise, 1.0% Cr and 0.50% Mn represents a balanced condition in the normalized state. However, in the as-rolled state, neither of these compositions is balanced; the finishing temperatures vary over a wide range and cooling rates are more indeterminate than generally considered proper for normalizing.

The addition of approximately 0.75% silicon tends to nullify the effect of variations in rolling practice and cooling, so that the above steels with this silicon content may be considered balanced in the as-rolled state as well as in the normalized state. It is interesting that the combined effect of chromium and manganese is such as to necessitate the preponderance of one or the other in the balanced compositions, as above indicated. Equal amounts, such as 0.80% Mn and 0.80% Cr will not, in general, result in a balanced composition in the as-rolled or normalized state. Properly heat treated, however, the steel will have physical properties such that the composition may well be considered balanced.

Some of the alloy steel types in current use are worthy of mention. The steels of 73,000 psi. maximum strength are: Medium manganese type with 1.4% manganese and 0.4% silicon; the plain chromium steel with 1% Cr, 0.35% Mn and 0.70% Si, and "cromansil" with 1.25% manganese, 0.50% chromium and 0.75% silicon. All of the above, with minor variations in the quantity of these three elements, and with or without copper, represent by far the largest tonnage of alloy steels for structural purposes produced in Europe and the United States.

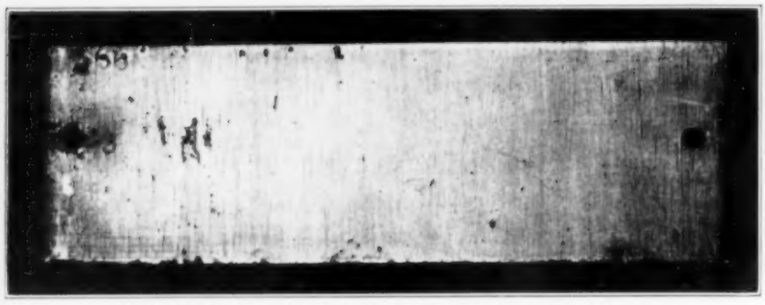
When higher strength is involved, such as 90,000 psi., the field becomes markedly limited. Most of the steels in the as-rolled condition require such an increase in the alloy or carbon content that the knee of curve corresponding to that shown in the first diagram is located below or at the desired strength. Disproportionate loss of ductility then results unless appropriate additions of the relatively expensive elements, such as molybdenum, tungsten, nickel, zirconium, vanadium, titanium, and columbium are made.

An exception is the cromansil type of steel, but even then in steel sections of appreciable size as-rolled, the knee of the curve is still to the right of the 90,000 psi. limit. Representative values were given by S. M. Norwood in METAL PROGRESS, September, 1934.

Heat Treated Steels

With quenched and drawn steels, the matter of balance is very much less important in tensile ranges up to 175,000 psi., such as are commonly used. Heat treatment can be adjusted to very wide limits of analysis so as to result in physical properties of satisfactory proportionate strength and ductility. This adjustment becomes more difficult above 175,000 psi., or where minor changes in ductility are of moment. Here such factors as grain size, mode of manufacture, as well as analysis, become increasingly important.

This is illustrated by carburizing steels in the range up to 175,000 psi. They include a number of modifications of the chromium-manganese variety having excellent properties; for example,



18% Cr, 0.40% Mn, 0.10% C; Fairly Good Resistance

18.2% Cr, 8.6% Ni, 0.46% Mn, 0.07% C; Good Resis

Specimens Exposed One Year in Air at 180° F., Relative Humidity 92%

1.5% Cr, 1% Mn, 0.5% Si, 0.15% C with fine grain size (probably obtained from a small vanadium addition) is eminently satisfactory for carburized articles subjected to dynamic stress.

Balanced steels for heat treatment have received less attention to date than have the as-rolled steels for a number of reasons. In the first place, heat treatment is adaptable to almost any reasonable steel used in engineering and, secondly, the service requirements of these steels are usually such that the engineer is loath to depend on the usual physical tests in order to select his steel. He would rather use materials with which he has had experience even though these may be somewhat more expensive.

Austenitic-Ferritic Stainless Steels

All of the above are in the category of low-alloy steels. Increasing the chromium to beyond 12% brings us to another category — namely, "stainless" steels. In plain high chromium steels, relatively low carbon is essential for ductile material, and as the steels are wholly ferritic, pearlite formation need not be considered in striking a proper balance of micro-constituents for optimum strength and ductility. Obviously, ferritic steel is possible only by practical elimination of the austenitic phase at any temperature.

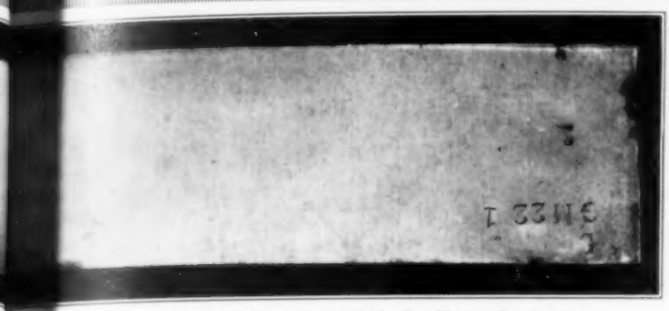
However, since ferrite is not as ductile as austenite, the problem of producing good ductility in stainless articles has so far been solved by steels which are predominantly austenitic at room temperature. The well-known 18% chromium, 8% nickel steel, as quenched, is typical.

As stated previously, manganese is a powerful austenite former, and by the proper balance of manganese and carbon it is possible to produce steels of high chromium content which are predominantly austenitic when quenched. Moreover, with such steels minor changes in the analysis or quenching practice enable the metallurgist to produce steel in which the ferritic constituent is present to a desirable degree. An 18% chromium, 8% manganese steel with 1% copper and 0.10% carbon, when rapidly cooled from 1925° F. (as, for instance, by air cooling of sheets or quenching of heavy sections) will result in a structure with approximately 60% austenite and 40% ferrite. That this must be so is apparent from the tri-axial diagram shown on page 49.

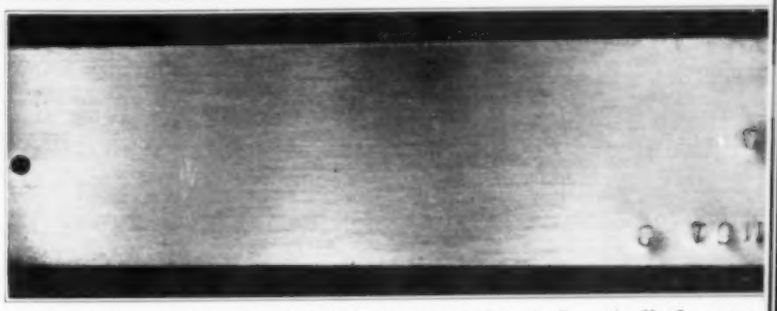
The question at once arises as to the usefulness of these austenitic-ferritic stainless steels. Do they meet the requirements, the ability to be fabricated and to remain stainless under a wide variety of conditions?

Consider first the matter of manufacture: Melting practice is favorably affected by the well-known property of manganese oxide to form fluid slags with silicates and chromium oxides, so that chromium steels with manganese are much more free from inclusions than those without it.

At forging temperature, the steel consists of a fine-grained aggregate of chromium austenite and chromium ferrite, and ferrite facilitates hot work. The tendency of chromium austenite to resist deformation at elevated temperatures is confirmed by creep tests, by short-time tensile tests, and by experience to the effect that steel which is fully chromium austenite at rolling temperatures requires more power for forging, and is more difficult to roll than a steel which is chromium ferrite. Thus, both theory and experience demonstrate greater ease of reduction from ingot to final hot-worked product of the two-phase chromium-manganese-copper steels.



17.8% Cr, 9.5% Mn, 0.90% Cu, 0.07% C; Very Resistant



17.8% Cr, 6.1% Mn, 3.8% Ni, 0.95% Cu, 0.07% C; Practically Immune

Specimens Exposed One Year in Air at 180° F., Relative Humidity 92%

Preparation of cold rolled strip is the next item to be considered. Austenite that is not in a highly stable condition, or that has been produced by arresting a natural change toward equilibrium by rapid cooling, has a marked tendency to change to a ferritic constituent and to harden on cold working. Perhaps the best example of this is Hadfield's 12% manganese steel. Ferrite also tends to harden on cold working, but to a lesser degree. Austenite, however, being more ductile than ferrite, will satisfactorily undergo an increased proportion of cold work. Mill experience has shown that in the cold rolling operations, the chromium-manganese steel consisting of 60% austenite and 40% ferrite hardens more rapidly than ferrite, but requires no greater number of anneals during cold reduction.

Production of stamped and formed articles is a more severe test because two-dimensional stress is involved. Austenite, being fundamentally more ductile than ferrite (because of the type of lattice) permits greater plastic deformation than ferrite before fracture occurs. Accordingly, the fully austenitic steels are superior to those having a high proportion of ferrite. When as much as 60% austenite is present and the matrix acts predominantly as austenite, the degree of difference in behavior in the stamping operation between the fully austenitic and the 60% austenitic steel is small. Actual tests, such as Erichsen cupping test, frequently show differences of 1 mm. or less, and plant production has shown ample deformability.

In machining operations, the same reasoning applies as in the cold rolling operations. The result is that the austenitic steels are much more difficult to machine than the ferritic steels, and the 60% austenitic chromium-manganese steel is somewhat more readily drilled, reamed and cut than though fully austenitic.

In welding several factors are involved. The ability of the metal to flow freely, protected by a slag sufficiently fluid to facilitate the operation is the first factor. Chromium oxide and slags high therein are highly refractory. This refractoriness is reduced by iron and nickel oxide to some extent, but much more markedly by manganese oxide. Thus, the welding of a chromium-manganese steel is a much simpler operation than the equivalent operation in high chromium steels with no manganese.

The matters of chromium loss and carbon pick-up during the welding operation are further factors. Here again the protection of the pool of deposited metal by the high manganese slag of lower viscosity protects the molten base metal from the oxy-acetylene flame or electric arc. Thus, somewhat less carbon pick-up and chromium loss can be expected, and this again has been confirmed by experience.

The next factor involved in welding relates to intercrystalline corrosion. Unstable chromium austenite tends to precipitate carbide when maintained at temperatures high enough to allow molecular freedom and low enough so that the austenite is supersaturated with carbide. This phenomenon takes place most readily at the grain boundaries where the maximum state of stress exists and molecular freedom in the lattice is greatest. Intergranular corrosion weakens grain boundaries, mechanically and chemically.

This phenomenon is directly related to a change in the austenite and does not occur in ferrite. Thus, with a steel containing 60% austenite and 40% ferrite only a portion of the matrix is affected. Actual tests on *(Cont. on page 74)*

Quenched Steel—

why is it so hard?

An account, in language not too scientific, of the development of the present theories concerning this most important metallurgical mystery. Throughout forty years of research the bounds of ignorance have been pushed back until we have a fairly clear conception of the structure of quenched steel, but still cannot explain so clearly why it is as hard as it is and no harder

HARDENING OF METAL IS A MUCH BROADER SUBJECT today than it was a generation ago. Then what we had to explain was why steel would harden after a quench and draw. Even though we cannot give a complete answer to that question, we know much more about steel than we did then — but at the same time we were studying steel we found out how to harden many other alloys by heat treatments, some quite unorthodox. So the problem of hardening should be considered in a very broad way. It is also natural that we fix our attention first on steel, and then take up some of the quite modern hardenable alloys.

There are many ideas regarding the hardening of steel still lurking in our minds which we inherit from the theories and the art of the past. Some of these ideas are still good, many of them are erroneous. As time has advanced our explanation of the phenomenon of hardness, both conferred and innate, has changed and perhaps has become simplified.

Steel hardening is very old as an art. If one made and shaped steel at all it was inevitable that little time would elapse before a piece came out hard, and hardness being a desirable quality, it was certain that attempts were made to repeat the process. One of the oldest records of the hardener's technique was unearthed in excavations at Tyre — a description of the method of hardening a sword for a high dignitary. A translation of this appears in the *Journal* of the Iron and Steel Institute of 1895, attributed to a Professor von Eulenspiegel in the following words:

"Let the high dignitary furnish an Ethiop of fair frame, and let him be bound down shoulders upward, upon the block of the God Bal-hal, his arms fastened underneath with thongs; a strap of goatskin over his back, and wound twice round the block; his feet close together lashed to a dowel of wood, and his head and neck projecting over and beyond the end of the block. Then let the master workman, having cold-hammered the blade to a smooth and thin edge, thrust it into the fire of the cedarwood coals, in and out, the while reciting the prayer to the God Bal-hal, until the steel be of the color of the red of the rising sun when he comes up over the desert toward the East, and then with a quick motion pass the same from the heel thereof to the point, six times through the most fleshy portion of the slave's back and thighs, when it shall have be-

By Francis B. Foley
Superintendent, Research Dept.
The Midvale Company
Philadelphia

come the color of the purple of the king. Then, if with one swing and one stroke of the right arm of the master workman it severs the head of the slave from his body, and display not nick nor crack along the edge, and the blade may be bent round about the body of a man and break not, it shall be accepted as a perfect weapon, sacred to the service of the God Bal-hal, and the owner thereof may thrust it into a scabbard of asses' skin, brazen with brass, and hung to a girdle of camels' wool dyed in royal purple."

Whether this is authentic or not, it is likely that swords could have been hardened in this way. Forgetting for the moment the inhumanity of the process, warm brine would probably have done just as well for quenching and another sort of test block could have served even better than a negro's neck. Swords having been made to cut off heads in those days, the test evidently was designed to simulate service conditions!

The ritualistic portion of the treatment is not astonishing, for the superstitious element in the art lasted for a long time. In fact, it is still with us. "Secret processes" smack of this sort of thing. Recently we received the following communication:

"I have a process that will recarbon any kind of steel from burnt steel, that is no good. By dipping it into my process it will make it the high carbon steel or better than it was at first, and also on the pulling strength. I will guarantee that it will pull twice as much as before. I will also take casted steel and dip it in my process and make it the same as hammered steel."

That writer was akin to old Cardanus, who wrote in 1557, "Steel is nobler than iron, and exists in two forms; namely, as made steel and as native steel. When it is well cleaned, then heated, and quenched three or four times in equal parts of extracts of radishes and water which has contained earth worms, it cuts iron like lead." Not many years ago I was asked by the inventor to verify a process he had evolved for hardening copper in a solution of hornbone and alcohol.

Francis B. Foley has been on production or research for the Midvale Co., America's fine steel pioneer, ever since 1905, except for the period 1917-26, when he was on War work and making oil well equipment

In all of these processes the user evidently goes on the assumption that the quenching medium adds something to the steel to aid in its hardening. That any true understanding of the nature of steel is quite modern is proved by the fact that although carbon was long known as an essential element, Sir Robert Hadfield has been able to find no systematic research as to the strength of steel containing different proportions of carbon earlier than 1869 (by T. E. Vickers in Kohn's "Iron and Steel Manufacture").

It took the microscope and the thermocouple to enable investigators to lay the foundations of a rational explanation of hardening. The thermocouple was useful in determining that steel had critical temperatures and in assuring reasonable repetition of experimental conditions as far as temperatures were concerned. The microscope showed that steel had characteristic internal structures depending principally on its hardness, composition, heat treatment, and amount of hot or cold work.

Even at that advanced stage the idea still prevailed that steel was rendered hard by the production in heating of some innately hard constituent existing above the critical point which was retained by rapid quenching. At first, it was "austenite" or "gamma iron" which caused hardness — these being merely names for the form in which hot steel existed — its essential nature being as yet unknown. It was soon realized, however, that austenite is not hard and, moreover, that it is a nonmagnetic form of iron, whereas hardened steel is magnetic. Then the hardness came to be attributed to the retention of "beta iron," a supposedly "allotropic" form of iron existing between about 1400° and 1650° F. in low carbon steel (the Ac_2 and Ac_3 tranformation temperatures, so called). There was another group of theorists who attributed hardening to the retention, upon quenching, of carbon in the form of a complex carbide to

Photo by William M. Rittase

Service Tests Are Good Tests, But of Little Use for Production Control

which the name "hardenite" and a formula something like $Fe_{24}C$ was given.

All these theories seemed to be based on the idea that ferrite was soft, that carbide was very hard, that the allotropic forms of iron existing at high temperature were of intermediate hardness, and that quenched steel was hard because some of these innately hard materials were retained at room temperature by rapid cooling.

No one had as yet sought to define hardness itself and all hardening theories were based on the behavior of plain carbon steel. The behavior of some alloy steels which, when quenched, turned out to be soft and which, when slowly cooled, were very hard, proved a stumbling block. However, the microscope by this time had furnished enough evidence to satisfy most of us by enabling metallurgists to label the structures "austenite" or "martensite." The steel was then hard because it was martensitic, and soft because it was ferritic or austenitic — obviously we had advanced a little, but were still concealing our ignorance behind a set of erudite names.

The advent of an alloy of aluminum known as duralumin introduced a new kind of hardening technique. Here was a different kind of metal entirely, a very soft metal, which was capable of being hardened by slight alloying and heat treatment. Soft when quenched, it hardened gradually but automatically upon aging at room temperature! Hardening was more rapid upon reheating to a low temperature. Theories now had to be broadened to explain not only the hardening of steel, but of other alloys as well, those of aluminum particularly.

Probably the clearest and most logical development came from a clear definition of hardness and led Jeffries and Archer to their "slip interference theory." This theory was not confined to the hardening of steel alone but to any metal. It is based on a definition of hardness which holds that hardness is resistance to permanent deformation; the first question that arises is "How do metals deform, once they have passed their elastic limit into the plastic stage where they acquire a permanent set?"

All solid metals consist of an infinite number of small crystals and they usually belong to the cubic system. That is to say, the atoms in each small crystal are regularly arranged along three perpendicular directions in space (the "space lattice"). Crystalline metals deform plastically by block slippage which occurs along certain "crystallographic planes" produced by the symmetrical arrangement of the atoms. There are certain planes of atoms within the crystals which act as though they are weaker than others and slip occurs first along such planes. (It should

be noted that there is ample evidence, both visual and otherwise, of the above statements — they are actual facts, not hypotheses.)

Were a piece of metal made up of but one crystal it would be necessary only to overcome the cohesion by proper shear stresses directed along the weakest plane to deform it permanently. However, if a number of crystals are present in the cross-section, the planes of atoms in the different crystals will take different directions in space, so that there will be no continuity of a single plane from crystal to crystal. The result is that movement along a given plane in one of the crystals (which plane may be disposed favorably for the occurrence of slip) is opposed by the adjacent crystals. It then will require a greater force to produce permanent deformation. Thus resistance to permanent deformation is increased by increasing the number of crystals in a cross-section — in other words, by decreasing the grain size.

Another method of increasing resistance to permanent deformation besides refining the grain is to introduce into a pure metal another element whose atoms may increase cohesion and, by virtue of their different size (or field of force), serve to roughen the otherwise regular crystalline planes and so to interfere with slip. Such added elements may combine to form a rather bulky chemical compound which, when dispersed throughout the metal, has the effect of keying the planes and thus greatly interfering with slip.

Slip itself may be used to harden metals, as in cold working. Cold work causes slip to occur in the planes most favorably oriented with respect to the stress which is applied. (It is understood, of course, that slip planes lose their cohesion only momentarily; the experimental fact that slip, once started, stops quickly and when it restarts it is on an adjoining plane has not yet been satisfactorily explained by the theorists.) When all planes which may yield under such applied stress have reached their limit in slipping, deformation ceases for that load and it is necessary to increase the load to cause slip in the next group of less favorably placed planes. When these have slipped to their limit, the stress must again be raised to produce further deformation. This, of course, may be carried on until failure results. But, if the load be removed before failure, it will be found upon reloading that it will require a greater load to deform the specimen permanently a given small amount than it did before the initial overloading.

All of the above methods, namely, grain refinement, alloying, cold work, may be resorted to in the hardening of steel.

Practically pure iron can be hardened by heat treatment only to a very limited extent. This is apparent from the following experiment on a sample analyzing carbon 0.03%, silicon trace, manganese 0.03%, phosphorus 0.007%, sulphur 0.014%, and copper 0.10%: When this piece was slowly cooled from 1700° F., its elastic limit and ultimate strength were 23,000 and 49,000 psi. respectively. When cooled in water these figures rose to 30,400 and 52,000 psi., and when cooled in iced brine they reached 42,800 and 67,400 psi.

This slight amount of hardening (or strengthening — the two are interrelated in theory and

Photo by John P. Mudd for the Midvale Co.

Research Into the Nature of Hardening Evidently Required a Measure of Hardness, yet the Indentation Method Was Not Introduced Until 1900

practice) is due practically entirely to the production of a smaller crystal size by the rapid quench, in turn made possible by the allotropic change occurring in iron from the "face-centered cubic" form of gamma iron to the "body-centered cubic" crystals of alpha iron as the steel cools through the critical range. Were it not for this allotropic change in the iron, steel would harden to a much more limited extent. The reduction of grain size which hardens pure iron is due to the fact that rapid quenching lowers the temperature of recrystallization (which is, of course, the critical temperature, A_3 in pure iron). Undercooling — or lowering of the temperature of recrystallization during cooling — produces small grains because the lower the temperature of such a transformation, the greater the number of crystal nuclei which form spontaneously.

Under ideal laboratory conditions and very slow changes in temperature, the transformation would occur during cooling at the same temperature as during heating. Were such conditions present the result of slow cooling would be the softest condition and the largest grain size.

A Caution as to "Grain Size"

Here let us not confuse austenitic grain size with the grain size of ferrite into which it transforms. It is generally understood that the grain size of steel depends primarily on the maximum temperature of heating and not on the cooling rate. This applies to the size of the crystals of austenite prior to passing through the recrystallization temperature range during cooling and, were it possible to cool rapidly enough to prevent this recrystallization during cooling, it would be *strictly* true. Recrystallization during cooling involves the formation of alpha iron and carbide of iron crystals, the size of which will depend primarily on the rate of cooling — the more rapid the cooling, the lower the temperature of recrystallization, and the smaller and more numerous the resultant crystals of alpha iron and carbide of iron.

Iron does not harden appreciably as a result of rapid cooling, because it is difficult to undercool it sufficiently — or, in other words, to depress the temperature of transformation. Fortunately the addition of carbon to iron has the effect of stabilizing or tending to render more permanent the austenitic form of the iron. Consequently, when the resultant steel is cooled rapidly it is possible to produce greater undercooling, so that recrystallization occurs near to atmospheric temperature. This results in a microstructure known as martensite.

The constitution of martensite is and has been for years a matter of considerable controversy among metallurgists. A series of important articles on the subject in METAL PROGRESS last August may well be re-read. There seems little doubt now that martensite is largely alpha iron, and that the alpha iron crystals, having been formed at very low temperature, are extremely small.

Practically all of the modern theories of hardening have been brought forward to explain the *hardness* of martensite, which is a much more controversial matter even than its structure. In the first place, we have an extremely fine crystal structure. Secondly, we have to consider the state of the carbon; it is in solid solution in the austenite, and we are faced with at least two possibilities when the austenite undergoes transformation at a very low temperature: The carbon may find its way out of the lattice to combine with the iron in the form of cementite or iron carbide, or it may be mechanically trapped in the transformed crystals. Thirdly, the volume change incident to the transformation from dense austenite to the less dense alpha iron causes, at the low temperature of transformation, considerable strain.

Any explanation of hardness must consider, therefore, fine grains, a dispersed constituent and a certain amount of cold working due to strain. No doubt there are also unstable transition forms in the crystallization of the iron from gamma to alpha and in the carbon from its solution in gamma iron to the ultimate orthorhombic compound cementite, and these may cause some of the controversy on the crystalline structure and cause of the hardness of martensite.

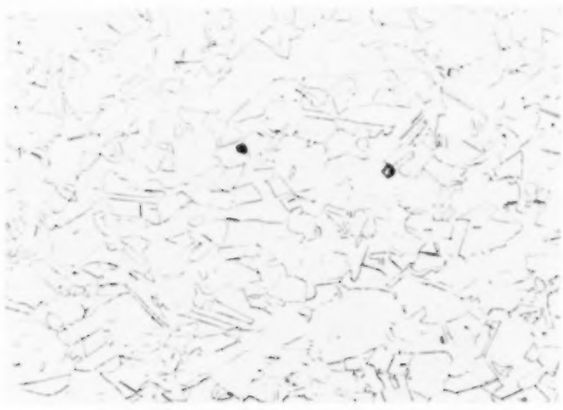
Although it has not been possible so far to separate the effects of the various factors, there is little question but that all the phenomena associated with the hardening of metals in general play some part in the hardening of steel. The passing out of solution of carbon and the formation of cementite are so inextricably tied up with iron's allotropic transformation that their separate effects are not known.

At any rate, the combination of the two changes, the allotropic change and the precipitation of carbon, makes steels capable of being produced in a wide range of properties, and while we can harden iron in other ways and with other alloys it is doubtful if anything will be found quite as useful as carbon.

METAL PROGRESS MARCH, 1936; PAGE 57

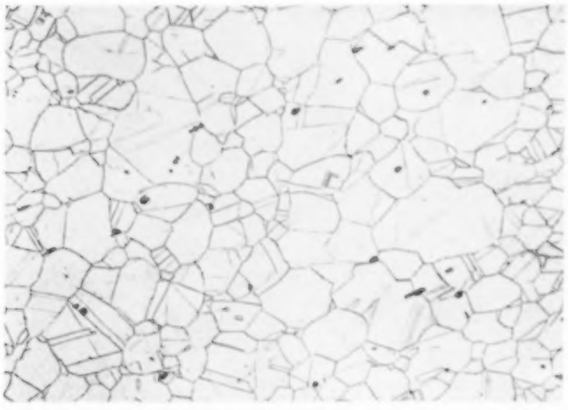
Microstructure of
Nickel and High Nickel-Chromium-Iron Alloys

Photomicrographs by Courtesy of Research Laboratory, International Nickel Co.



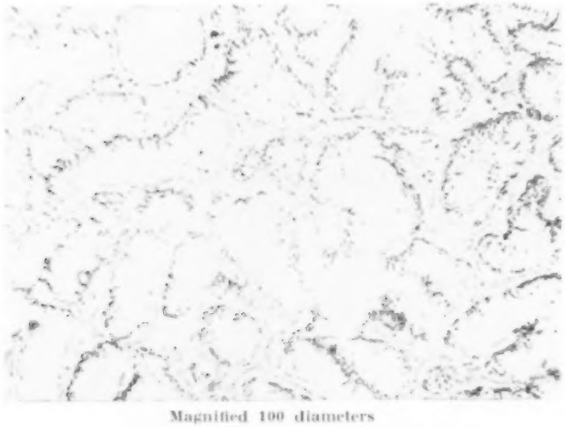
Nickel, Hot Rolled

Etched with equal parts of nitric and acetic acid; magnified 100 diameters. Analysis: 0.12% C, 0.11% Mn, 0.03% Si, 0.10% Cu, 0.11% Fe, 0.005% S.

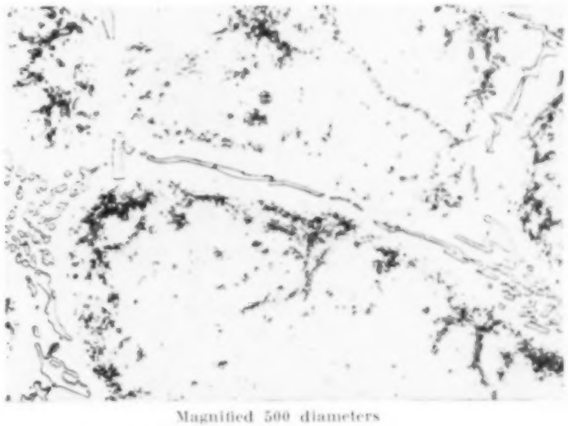


Inconel, Rolled and Annealed

One-quarter hard (Rockwell B-87), 0.062-in. strip. Etched in mixture of hydrofluoric and nitric acid; magnified 100 diameters. Nominal analysis: 80% Ni, 12 to 14% Cr, 6% Fe.



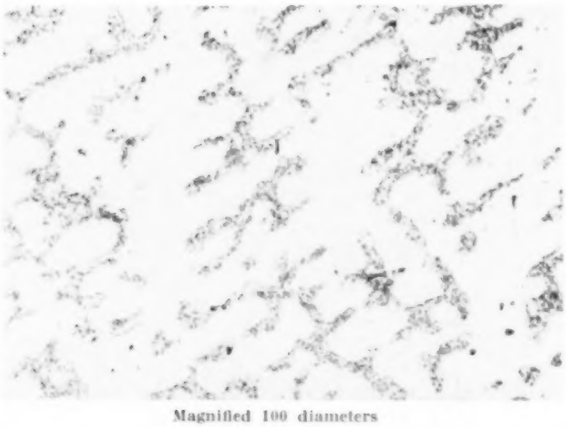
Magnified 100 diameters



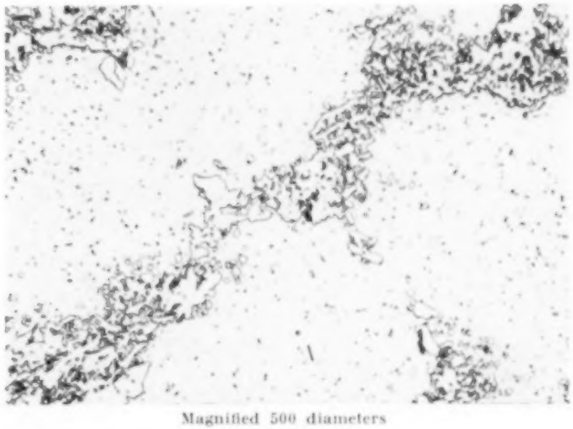
Magnified 500 diameters

Cast Alloy of Nichrome Type for Heat Resistance

¾-in. casting, etched in aqua regia. Analysis: 60% Ni, 15% Cr, 23.5% Fe, 0.5% C, 0.5% Mn, 0.5% Si.



Magnified 100 diameters

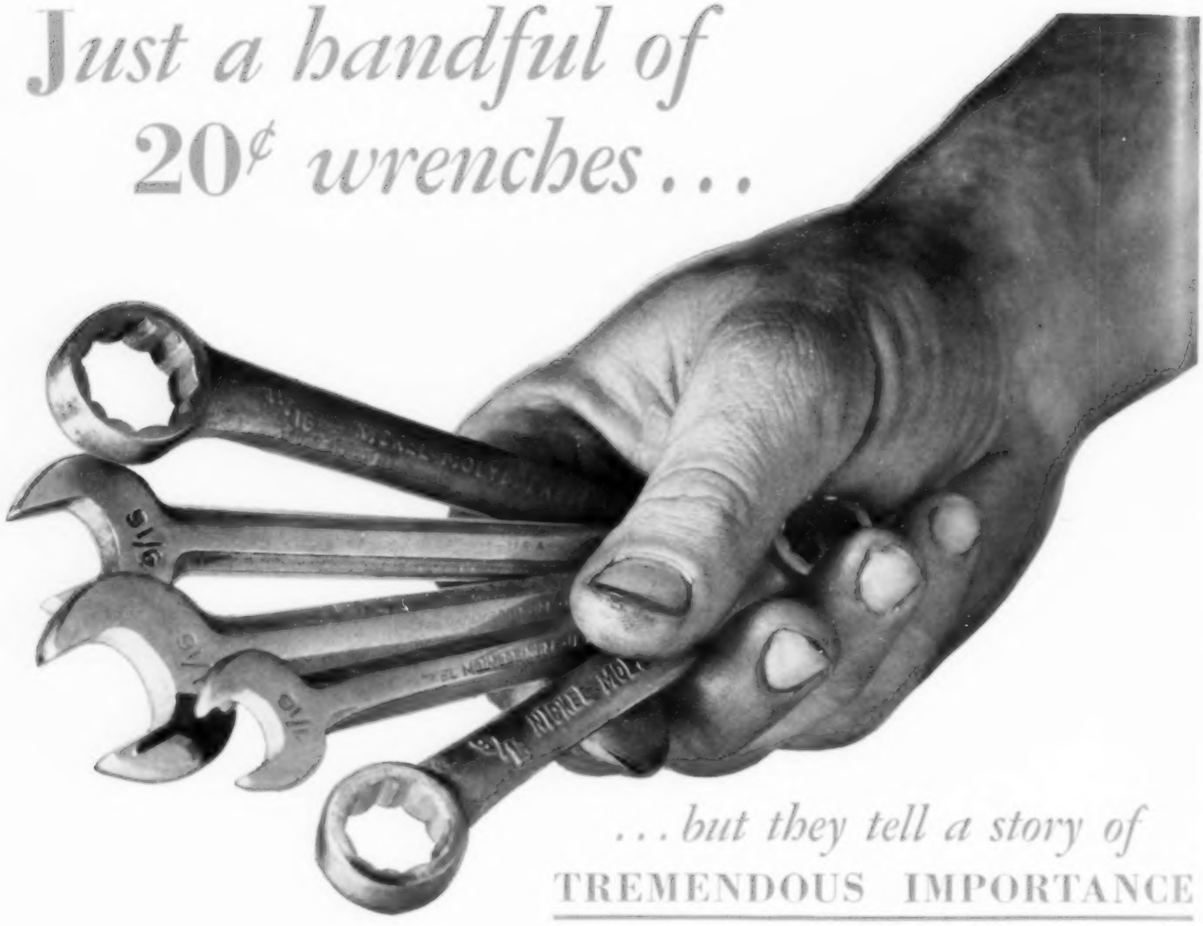


Magnified 500 diameters

Cast 35-18 Alloy for Heat Resistance

¾-in. casting, etched in aqua regia. Analysis: 35% Ni, 18% Cr, 44.5% Fe, 0.5% C, 0.5% Mn, 1.5% Si.

Just a handful of 20¢ wrenches . . .



. . . but they tell a story of
TREMENDOUS IMPORTANCE
to industry

THE wrenches pictured above were purchased at Woolworth's. They cost 20¢ apiece. Stamped on the shank of each are the words, "Nickel-molybdenum steel."

Fancy being able to buy Nickel Alloy Steels for so little! Fancy finding this aristocrat of modern metals on the counters of the "five-and-tens"!

The same steels that are so widely used by the automobile industry to give vital parts of cars and trucks greater strength and endurance.

The same Nickel Alloy Steels that add longer life to scores of heavy duty parts in machinery of every kind.

The International Nickel Company is delighted to print the fact that Woolworth sells Nickel Alloy Steel products. For, more forcefully than pen can write or tongue can tell, it proves a tremendously important point. It proves that steels containing Nickel are NOT EXPENSIVE.

For if Woolworth's can sell heat-treated Nickel Alloy Steels and make a profit, industry at large can easily afford to enjoy their marked advantages.

Furthermore, if as small a tool as a wrench is considered important enough to warrant the use of Nickel, how much *more important* it is to use Nickel in your more vital applications.

NICKEL ALLOY STEELS

THE INTERNATIONAL NICKEL COMPANY, INC., 67 WALL STREET, NEW YORK, N. Y.

Heat Treated Rails

for special trackwork

Wear at crossings in railroad tracks of all kinds has been a serious problem, best solved in the past by using cast manganese steel frogs or inserts. Rails are, however, made of a good quality of high carbon steel and this article shows how crossings made of standard rail sections can be greatly improved against wear by heat treating the rails, filler blocks and bolts

STANDARD RAILROAD RAIL IS, ON THE WHOLE, GIVING very good service, as proved by the reliability and extreme safety of railroad traffic. Special trackwork, however, comprising switches, frogs, and crossings, where the wheel loads are transferred from one rail to another, obviously receives much more severe usage, and the manufacturers of this material have long striven to improve its life and service. In rail crossings, particularly when the lines make an angle between 45° and 90°, this usage is extremely severe due to the intersecting flangeways which the wheels must literally jump over, resulting in terrific impacts with the loads and speeds of present-day railroading.

It follows that there are many things besides suitable rail steel required to make a durable frog or crossing and to keep it lined up and tight. Nevertheless, good steel is obviously a prime essential. A little wear at the flangeways increases the impact, starting a vicious cycle — it grows like a chuck hole in a pavement until traffic is seriously endangered and accidents invited.

Railroad engineers have faced this problem of more durable rail under constantly increasing wheel loads for many years. They have met the situation by steadily increasing the carbon in the steel for greater hardness and strength until the present standard specification for heaviest rail is 0.72 to 0.89% carbon. Silicon has been gradually increased to 0.15% or more, primarily to insure soundness, but this has also had an unmistakable effect on hardness. Manganese is also fairly high, 0.50 to 0.90%. This means that the principal raw material used for frogs and crossings is the plain high carbon steel rail of main line track, as high in carbon as some tool steels, but, being air cooled from the rolling mill, it is received in a comparatively soft state.

Now main track is usually relaid, not because the rails are worn throughout their length, but because the ends are battered and worn so that a smooth running surface cannot be maintained. If batter is the prime cause of deterioration where ends can be butted closely, how much more serious it must be in places where a gap must be left to pass flanges of wheels. This is the problem with which the frog and crossing manufacturer has to contend.

Mention should be made of the use of alloy steel for trackwork, especially since the cast Hadfield's manganese steel (manganese 10.0 to 14.0%, car-

By Edwin W. Goodaire
Works Manager
Cleveland Frog & Crossing Co.

bon 1.00 to 1.40%, and silicon 0.30 to 1.00%) is very widely used for frogs and crossings. This material, quite brittle as cast, becomes extraordinarily tough when water quenched from about 1925° F.; its abrasion resistance is due to the fact that this tough alloy transforms spontaneously into an excessively hard material when it is slightly deformed plastically by battering. It performs excellently in special trackwork under heavy, fast traffic, and is the favored material for sharp frogs, small-angle crossings, or close intersections where a built-up assemblage of rails and fillers would require very long bolts.

Several factors other than the cost of alloying metals conspire to make cast manganese frogs and crossings rather expensive. On all special work, patterns must be made and as they are frequently used only once the pattern expense is high. Furthermore, the castings from the foundry can be machined only by grinding; consequently it is expensive to surface the castings and fit them into the rails.

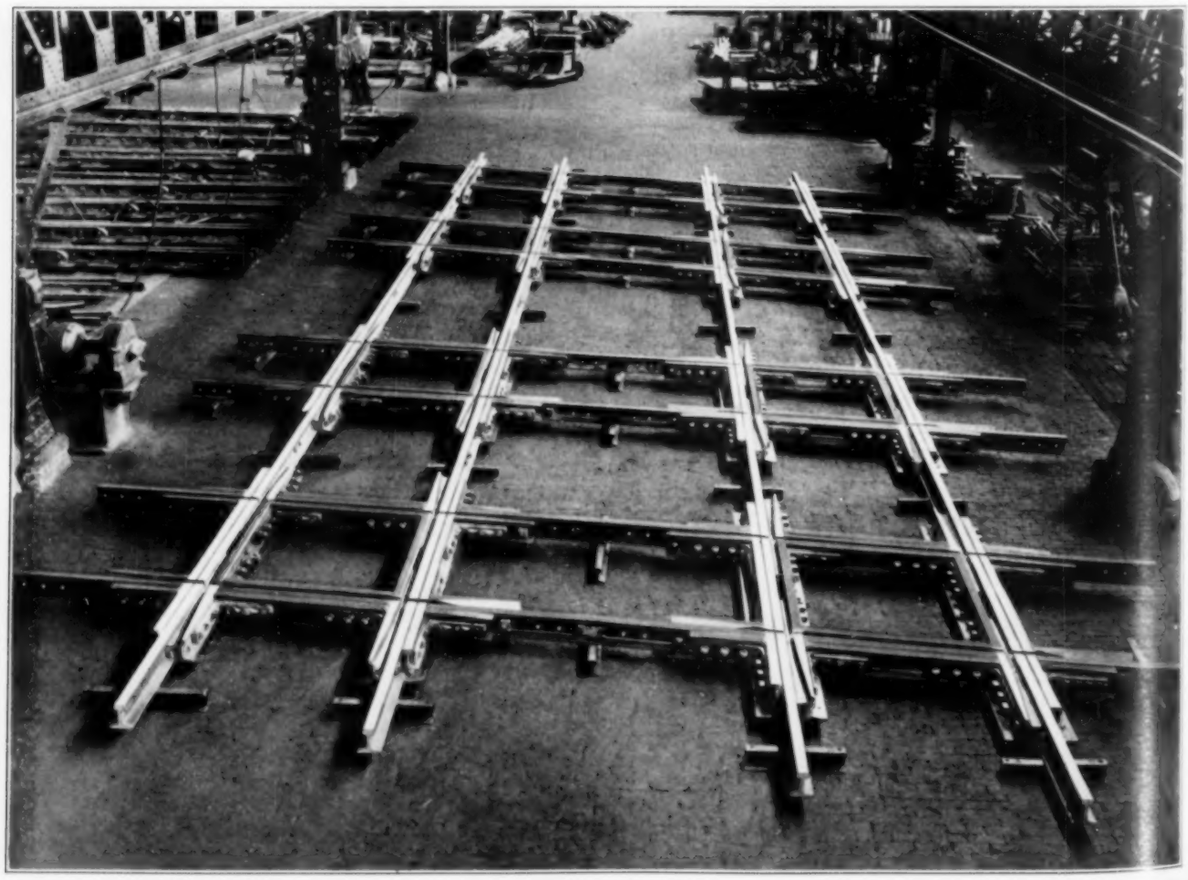
Cast manganese special work is therefore usually confined to the heavy, high speed traffic and sharp angled intersections, or to places where renewals are very expensive or troublesome, as in tracks buried in city pavements, or in approaches to busy terminals. Whether cast manganese or bolted rail special trackwork should be installed is a problem which must be solved for each case as it arises.

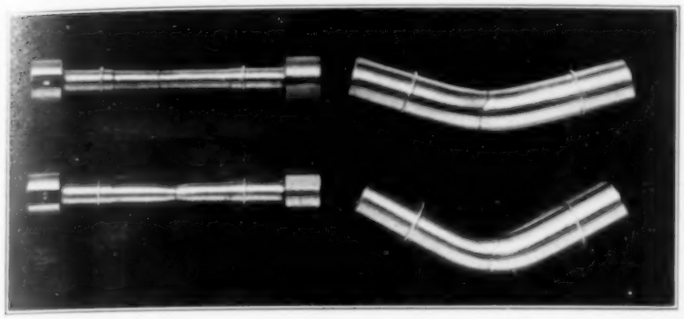
It is perhaps not very well known, but many thousand tons of rail have been rolled from Hadfield's composition and placed in track where wear is unusually severe (due to brakes, driving wheel slippage, or scour from flanges on sharp curves). This is known in the trade as "rolled manganese rail." It has also been built into special trackwork but it cannot be said with entire satisfaction. In the first place, it is extremely difficult to work — it can be cut with high speed friction disk saws, but finish machining must be done by grinding. Bolt holes can only be drilled in the web with difficulty, using a massive drill press and special cobalt high speed drills. Finally, the material is not uniform; some crossings have given all the anticipated life, but others in almost identical service have not proven so satisfactory.

Possibilities of the hard chromium steels and chromium-nickel steels for special trackwork have already been explored in the form of heat treated castings for special trackwork for street-car lines, but these have never been thought suitable for steam railroad service.

This, then, was the situation as it existed some five or six years ago: There was no material intermediate in price and durability between the

A Group of Eight Crossings on Assembling Floor; Heat Treated Rails Are Painted White





Rail Steel, as Rolled, Is Simultaneously Strengthened, Hardened and Toughened by the Proper Heat Treatment

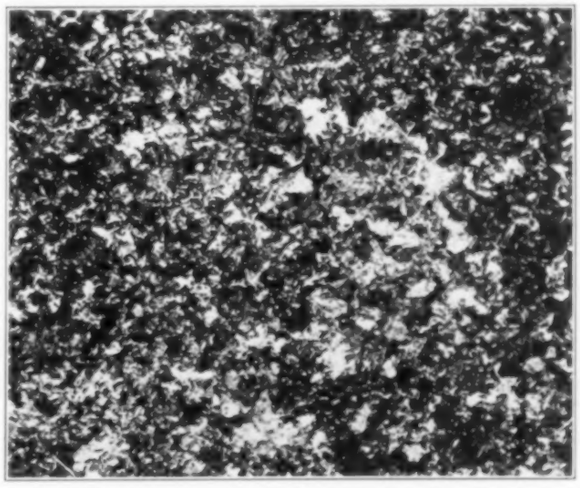
	Upper Specimens as Rolled	Lower Specimens Heat Treated
Brinell hardness	255	363
Ultimate strength, psi.	131,000	165,000
Elastic limit, psi.	88,000	127,000
Elongation in 2 in.	11.7%	14.0%
Reduction of area	16.6%	39.1%
Angle of bend	30°	56°
Load at break, lb.	22,300	33,200

expensive cast manganese inserts and the comparatively short-lived special trackwork built up of standard rail. However, since this standard rail is the approximate equivalent, chemically, of tool steels for sledges and all sorts of battering tools, it was certain that its hardness and abrasion resistance could be greatly improved by proper heat treatment (quench and draw) without sacrificing any toughness.

Heat Treated Rail

Heat treatment of rail in long lengths as it comes from the rolling mill has been studied extensively by the steel mills both here and abroad. It would take us too far afield to discuss the many methods proposed — or even the few that have been tried in a commercial way. We at the Cleveland Frog & Crossing Co. were of the opinion that if the hardness of the rail head of around 250 Brinell as rolled could be increased to about 350, the durability of crossings fabricated from it would be vastly increased. Following out this idea we made and heat treated some running rails in 1930 for a crossing originally made of rolled high manganese rail which had mashed down in a comparatively short time. Within a year the heat treated rail had definitely proven its durability, and, in fact, these renewal rails are still in track after carrying the traffic over five years.

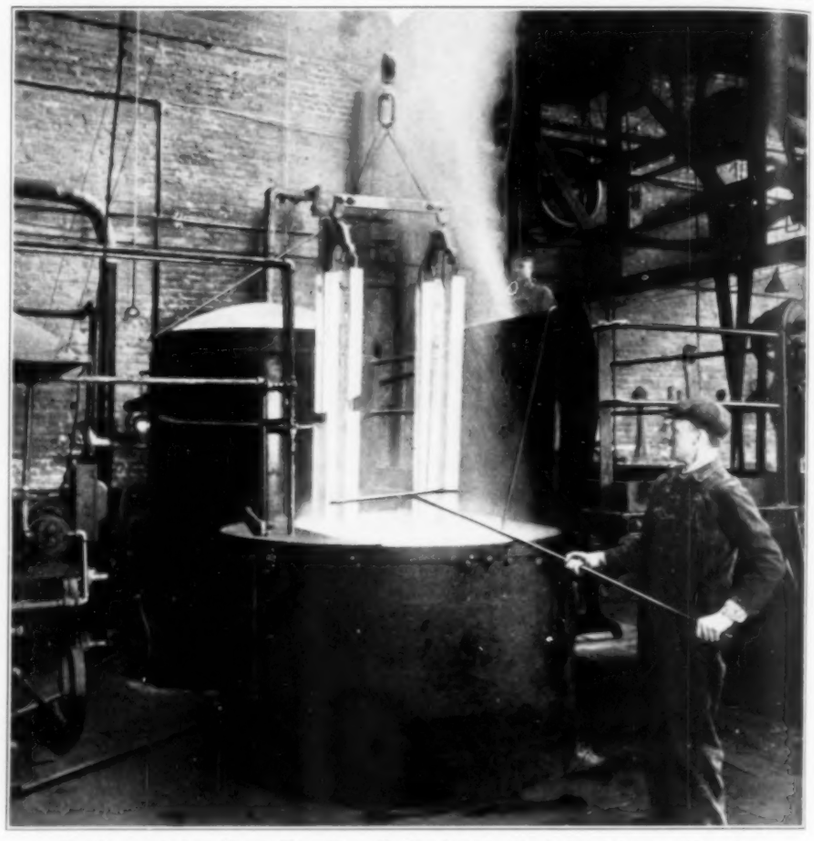
Manufacturers of special trackwork and maintenance of way engineers have hesitated to use heat treated rail in crossings because of the tremendous impacts which the material in these structures must withstand, believing that this hardened rail must necessarily be relatively brittle and therefore more liable to fracture than the untreated rail, and consequently a possible source



Microstructure of Rail as Rolled and After Heat Treatment. Etched with 1% nitric acid in alcohol; magnified 100 dia. Above is so-called nodular troostite in air cooled rail as rolled; if properly magnified this is resolved into fine pearlite (as proven by F. F. Lucas in Metal Progress *for February, 1935). Below is the much finer grained structure after heat treatment; there is some pearlite formed during the oil quench but much of the austenite has changed to hard martensite and this later transformed into tough sorbite (finest granules of carbide in ferrite) on tempering*

of danger. However, after numerous metallurgical and physical tests of specimens of heat treated rail we proved to our satisfaction that rail could be hardened *and at the same time rendered tougher* than before treatment, resulting in a material which is not only better adapted to withstand the abuse to which crossing intersections are subjected but is safer than untreated rail.

To many persons experienced with carbon tool steels this simultaneous increase in hardness and toughness (or ductility as measured by elongation and reduction of area in a tension test) may seem impossible. It is ordinarily understood that as hardness and strength of a steel go up, the ductility and toughness go down. That is indeed true if one quenched and tempered piece be compared with another quenched and tempered piece. It should be remembered, however, that we are comparing a heavy rail *as rolled* with another after it has been greatly improved by proper heat treatment.



Equipment for Heat Treating Rails in Vertical Position. Circular furnace in background has beams of heat resisting alloy near top on which rest the yokes carrying the rails. Quick transfer to oil quenching tank, extending 10 ft. below floor, is made by overhead trolley

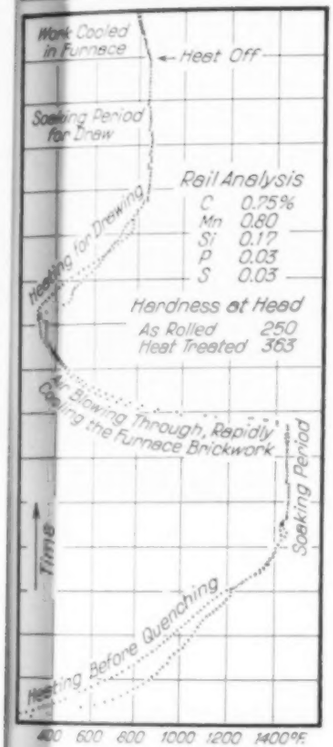
Superiority is also shown by bending tests on 1-in. rounds cut from rails and bent as a beam with 5-in. span (page 61). The rail steel as rolled broke at 30° bend and 22,300 lb. concentrated load at mid-span; the same steel, heat treated to a greater hardness, broke at 56° bend and 33,200 lb. load.

For crossings we desired to use quenched and tempered rails, with a fine grained structure containing as much true sorbite as possible, rather than a coarser grained aggregate consisting of fine pearlite. Metallographers agree that the sorbitic structure has superior toughness when the hardness is equal. This toughness in our rails can be inferred from the greatly enhanced figures for elongation and reduction of area in the tension test. Practically it may be demonstrated any day by the action of the rails in a straightening or bending press.

It remained for us to devise the manufacturing process best suited to our purpose. We could buy heat treated rails from the rail mills, but the added difficulty of machining, curving or straightening them and the danger of breakage decided against this plan. So we machined all parts of the crossing to close fit and heat treated those portions which had to bear the heavy traffic — running rails, easer rails (or rails back of the running rails to pick up wheels unduly worn near the flanges), and those guard rails that took impact of wheels on the secondary track.

Flangeway fillers on the main line are also heat treated even though they are not touched by passing wheels. The reason for this is as follows: The various parts of a bolted crossing, no matter how tightly assembled, will rub against each other by the ever-so-slight movements caused by passing wheels. This rubbing means wear, and

ultimate looseness is caused by actual loss of metal rather than stretching bolts or turned nuts. When nuts are tightened to take up this wear, it reduces the gage of track below the standard 4 ft. 8½ in., and decreases the flangeway width. Therefore all filler blocks in a high grade crossing are machined for a snug metal-to-metal fit on all sides, and then hardened to resist wear. Rolled bars of proper shape to fit the standard rail sections are available, but are not very satisfactory for heat treatment as the outer surfaces are slightly decarburized. We therefore plane these fillers from 0.40 to 0.50% carbon steel billets and harden to approximately 285 Brinell.



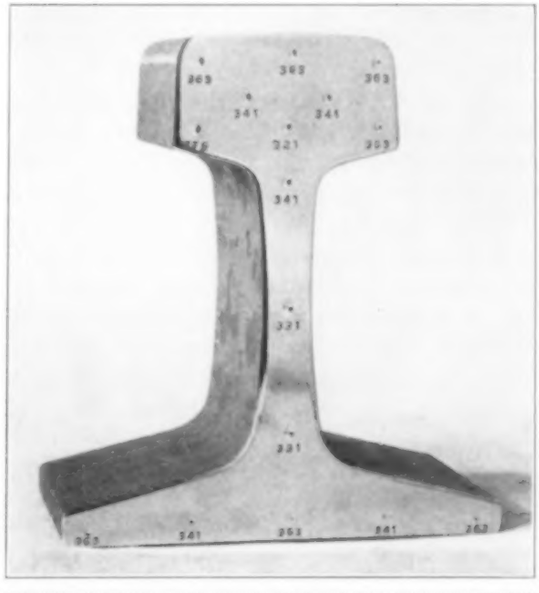
Representative Pyrometer Chart From Furnace During One Cycle of Quench and Draw. Note two control points. Rapid changes in furnace temperature are permitted by building it of insulating refractory brick

Our early heat treating was done in an outside plant having a large hearth furnace. Even though the greatest care was taken to support the rails in a horizontal plane, they would warp considerably in the furnace and no matter whether quenched head up or head down, would require a great deal of straightening after heat treatment. Even when quenched vertically, the hot rail would sag a little when pulled out of the furnace and picked up by one end. The punishment that these hardened rails withstood in this straightening further convinced us that we had a safer, as well as a harder, material. The same rail not treated would have broken long before we got to the pressures and deflection necessary to bend the treated rail beyond its elastic limit so it would acquire a permanent set. Since the rail performs like spring steel in this hardened condition, we felt that we were subjecting the rail to serious strain and were very liable to damage it even though it did not break, and in order to minimize this straightening we installed equipment to handle this work vertically, like a gun tube in an ordnance shop. It has been very satisfactory, for practically no straightening is now required.

As shown in the accompanying view, the furnace is built in a cylindrical steel shell 5 ft. 6 in. in diameter and 9 ft. high, reinforced inside at top by a 4½-in. angle, bent into a ring. The roof or cover can be raised and swung aside by a simple jib crane. The flue is an 8-in. pipe out of the center of the bottom. Fuel is natural gas, entering in eight burners, set alternately at opposite sides and about 12 in. apart in elevation, each directing a flame in tangential manner so that the hot gases swirl about inside, heating the brickwork. Control is had by Leeds & Northrup equipment using two pyrometers at the axis of the furnace, one near the top, one near the bottom. A compressed air line was introduced into the flue for injector effect so that draft might be obtained; this, with a damper in the flue, gives us complete control of the temperature throughout the height of the furnace.

Since the furnace is used intermittently and for both quenching and drawing heat, it was necessary that the brick walls store as

Exploration of Cross-Section of Heat Treated Rail Shows Hardness to Be Quite Uniform Except, as Expected, at Center of Head. Low value at center of web shows that this portion does not cool too rapidly and harden unduly



little heat as possible. Hence it was lined with 9-in. Babcock & Wilcox insulating refractory brick. The pyrometer curve on page 63 shows that a cold furnace can be loaded in the morning, brought to temperature, 1450° F., soaked 90 min., and the work quenched by noon. The gas is then turned off, but combustion air left blowing for its cooling effect. Shortly after lunch hour the furnace, now cooled to about 300° F., is reloaded, reheated to drawing temperature (850° F.) in 60 min., and held for 90 min., when gas and air are turned off and the charge left in the furnace over night to cool slowly. These temperatures are adjusted as necessary to correspond to the chemical composition of the rail being treated.

Quenching Practice

About 12 in. below the top of the furnace is placed a pair of crossbeams from which the work is hung by appropriate yokes. As designed, the vertical furnace will accommodate rails up to 7 ft. 6 in. long. Work is rapidly transferred by a 1-ton electric trolley hoist to the oil quenching tank alongside, 6 ft. diameter by 14 ft. deep. This quick transfer permits the use of minimum heating over the critical point, which gives the finest grained structure. The vertical movement of the rail in the oil aids the conduction of the heat uniformly from all parts of the rail.

We adopted oil quenching, rather than water quenching, because we felt that the latter was somewhat too drastic for the high carbon rail steel. To prevent edge cracks even in oil quenching, we countersink slightly all drilled holes, and round all sharp corners or edges produced by planing or sawing operations.

An accurate record of the analysis of the rail used for heat treatment is kept and rail of one analysis only is treated in each charge, and temperatures are used which have been established for this analysis. With this procedure we are able to obtain consistently a hardness of between 341 and 363 Brinell, and the great majority of our rail is nearer the higher hardness. Hardness throughout the entire cross-section is surprisingly uniform, which is a further indication that the rail is free from unbalanced internal strains, and therefore a safe rail to use.

Now that the so-called "box cooled" rail is available (that is, rail which is cooled at a controlled rate through the blue critical range on hot beds at the mill), we use only this special rail for heat treating when it is available. It is important that *(Continued on page 92)*

Weakening of Metal by Molten Solder

By G. Wesley Austin

Condensed from Journal Institute of Metals

THE AUTHOR'S ATTENTION WAS DIRECTED TO THIS phenomenon in 1928 by frequent breakages of high tensile brass fittings while being soldered and screwed into position, and by the unexpected fracture of a high tensile alloy steel cylindrical shell. Solder was subsequently found on the fracture face of the latter.

The operation of soldering is carried out so extensively in engineering practice that it was decided to investigate, quantitatively if possible, the susceptibility of the commoner metals and alloys to the combined effects of stress and molten solder. Tension tests were therefore made while the specimen was immersed in molten solder, tin and some other metals at given temperatures between 450 and 1200° F. In all cases a companion specimen was tested in oil at the same temperature. Autographic stress-strain curves were drawn, whereby it was possible to determine at which stage of the load-extension curve (elastic, general stretching to maximum load, or necking) the effect, if any, occurred, and whether the normal tensile flow curve was interrupted only, or modified.

Six metals, 10 non-ferrous alloys, and 16 steels (some at various hardnesses and grain sizes and also in the burnt and temper brittle states) were tested. From a voluminous set of data and stress-strain curves the following conclusions may be drawn:

1. Almost all the usual metals, alloys, and steels employed in general engineering, if stressed in tension and in contact with molten solder, are susceptible to penetration and weakening to a greater or less degree. Nickel, monel metal, and cupro-nickel are, however, but slightly affected by the solder.

2. The plain low carbon steels, and the lower carbon, either pearlitic or austenitic, heat and rust resisting steels, do not appear as subject to penetration as similar steels with higher carbon. The liability to penetration in the heat treated alloy steels tested becomes greater with increasing hardness and secondary grain size, especially

(Continued on page 90)

Letters from Abroad

Oxygen and Oxides Segregate In Reverse to Sulphur

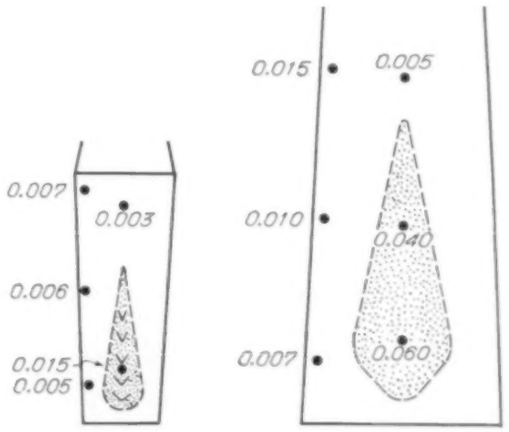
PARIS, FRANCE — So many improvements have recently been made in the analytical methods for determining oxygen in steel (see, for instance, METAL PROGRESS for April, 1932, p. 74) that it is now possible to acquire precise data on the primary segregation of oxygen and oxides in the ingot, by analyzing samples taken from various places. Such studies have been frequently made in the past, especially for carbon, phosphorus and sulphur, and it now develops that oxygen does not segregate in the same manner and to the same degree as some other impurities, such as sulphur.

In general, it has been found that a zone rich in oxygen may be found along the lower axis of the ingot, the oxygen content steadily rising to its highest values near the base. On the other hand, if samples are taken near the surface of the ingot, the lowest values may be near the base and the highest near the top. Of course, the primary segregation of oxygen, as of other elements in the steel, depends not only on the analysis and its state of deoxidation (whether killed or rising) but also on the forms of the isotherms during solidification. The latter relates to several factors, such as the weight of the ingot, its proportion of area to height, the amount and direction of taper, and the mass and temperature of stool, mold, and sinkhead.

In order to fix our ideas, let us take two specific examples, sketched in the diagram.

First is a slender ½-ton ingot of mild steel, made in an electric furnace, cast big end up with an insulating sinkhead. The sketch shows the results of several oxygen analyses, wherein it would appear that a deep-seated pyramidal segregated zone exists along the lower axis, corresponding to the region of small dendrites. (In this zone are also found the so-called V-segregations.) In this zone the oxygen is on the order of 0.015%, whereas at the top center of the ingot it is hardly one-fifth as much. At the surface, on the other hand, the average is lower, and the individual analyses *increase* slightly from the base to the top.

The second is a much more massive ingot, weighing several tons, of Thomas steel (basic bessemer). This was cast big end down without hot top or shrinkage head. The pyramidal segregation zone along the lower axis is again found, extending further toward the top, and the average and maximum oxygen content of this zone is very much higher than in the first illustration. It will also be observed that the oxygen analyses



Segregated Zone of Oxygen and Oxides Along Axis of Commercial Ingots Reverses Variations Along the Surface. Left: ½-ton electric steel ingot; right: 5-ton basic bessemer steel ingot

at the top center and along the surface, while also substantially higher than in the small electric ingot, bear the same relationships to each other.

Thus in these two very different examples, the maximum variation edge to center is found near the ingot base, and in the large ingot the difference is on the order of ten-fold. The situation is reversed at the top, where the surface is two or three times as rich in oxygen as the section at the axis.

Now in view of the very slight solubility of oxygen in steel, particularly in the presence of such deoxidizers as silicon and aluminum, the bulk of this oxygen obviously depends on the number and size of oxidized inclusions present. It is also worthy of emphasis that the terms "impure zone" or "segregation zone of an ingot" have no precise meaning unless the element or impurity in mind is also specified. Thus the central region near the top of an ingot is a zone rather poor in oxygen, yet rich in other elements such as sulphur and carbon. In fact, the distribution of oxygen appears to be almost exactly the reverse of sulphur.

It should also be noted that there is little or no basis for any classification of the various manufacturing processes as to their ability to make quality steel by making a random analysis for oxygen. It is necessary to specify the type of ingot and the location of the sample in order to have a true basis of comparison.

For the above reasons it is quite likely that many errors have been made and false impressions created by those who have tried to connect the properties and quality of steel with the oxygen content. It also follows that it is now impossible with fairness and accuracy to introduce into purchase or acceptance specifications any general requirement as to oxygen content or any test purporting to show the approximate state of deoxidation.

ALBERT PORTEVIN

Flakes in Steel

A QUESTION WAS RECENTLY RAISED BY A CORRESPONDENT as to the accuracy of the temperatures quoted in Dr. Diergarten's recent letters about investigations by the Krupp staff on the origin and nature of flakes. Houdremont and Korschan's account of their investigation, published in *Stahl und Eisen*, does not quote any temperature scale in the text but does show the Centigrade scale on one of the diagrams. In view of the common use of this scale in Germany, it is certain that they were not misquoted in stating that the dangerous temperature for flake formation is about 200° C., or as translated in METAL PROGRESS, 400° F., more or less.

It should also be noted that H. Bennek, H. Schenck and H. Müller also participated in the investigations and should have been mentioned in the second letter (September, 1935) as they were in the first (July).

THE EDITOR

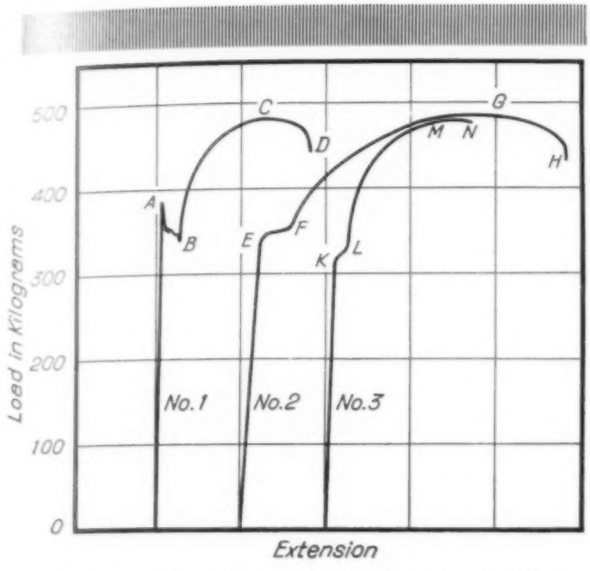
Does Upper and Lower Yield Point Have Actual Existence?

WARSAW, POLAND — A considerable literature is available about the changes taking place in iron or soft steel at the yield point. It is well known that the test piece suddenly yields to a remarkable degree, and if the work is done in a lever or weighing type of testing machine, this occurrence is noted by the "fall of the beam." If plate or sheet with mill scale or whitewashed surfaces is tested or strained beyond the elastic limit, there appear simultaneously with the yield point some characteristic surface markings usually called Lüder's lines.

Stress-strain diagrams drawn automatically by tensile testing machines either of the lever or the hydraulic type also have a characteristic shape. One such is given at the left of the accompanying engraving. Testing engineers have become accustomed to the shape of these curves, and are no longer struck by the contradictory features presented between points *A* and *B*, and points *C* and *D*. Diagrams have been recorded in the German literature where the difference between the "upper yield point" and the "lower yield point" (points *A* and *B* respectively) is as much as 30% or even 40% of the former, and where point *A* is actually higher than point *C*! Likewise other diagrams would indicate that the breaking load (point *D*) is 30 to 50% less than the maximum load at *C*.

It is not conceivable that these diagrams represent the true properties of the material, for there can be no actual drop in real stress up to the breaking point. It is hardly imaginable that the load once applied should drop in such a conspicuous manner due to an internal yield.

In order to verify the conclusion that the shape of the stress-strain curve between *A* and *B* and between *C* and *D* is caused by certain pecul-



Autographic Stress-Strain Curves for Identical Test Pieces of Soft Steel in Three Machines Where Rate of Elongation of Test Piece Has Progressively Less and Less Influence on Recorded Load

iarities in the design of the machine and not by plastic flow of the steel, some small test pieces were prepared within the breaking ability of three equipments later to be described. These test pieces were 5.5 in. between heads, shaped to fit ball and socket grips, and were tapered gradually down to a reduced section 3.5 mm. diameter by 65 mm. long (0.138x2.56 in.). The material was a 0.15% carbon steel annealed at approximately 800° C. (1475° F.). The breaking load for the test piece was 470 kg., corresponding to an ultimate stress of about 54,000 psi.

The first diagram represents the curve automatically recorded on a 5-ton Amsler tensile machine with weight pendulum and load indicator. The dynamometer of the machine was set to a maximum load of 500 kg., and the diagram was therefore recorded on an adequately large scale. As in most tensile testing machines of this kind, a very small motion of the head will correspond to a comparatively large load shown on the dynamometer — in this case a motion of but 1.1 mm. (0.043 in.) is necessary to increase the load 500 kg. In other words, if the test bar suddenly lengthens at the yield point by as little as 0.1 mm. when under a load of 370 kg., the load indicator — and the actual load — will drop to approximately 320 kg.

Believing, therefore, that the stress-strain line between *A* and *B* is due to this construction of the machine, an identical test piece was tested in a small Amsler machine for testing sheet steel, wherein the ratio between the head travel and the load is 40 times as great as in the one previously used. This machine also has a load indicator and is designed for a maximum load of 500 kg. Owing to the construction of this machine a sudden elongation of 0.1 mm. will cause the load to drop only a little more than 1 kg.

The self-drawn stress-strain curve for this test is shown in the center, and it is obvious that there is no upper or lower yield point to be recorded. The steel begins to elongate rapidly at *E*, but the load *does not drop* between *E* and *F*. On the contrary, it is worthy of emphasis that the load rises during the yielding interval, even though little, yet steadily and uniformly.

Even in this equipment the portion of the curve just before fracture (*G* to *H*) shows a fictitious downward course, as is proven by the third curve, taken on an identical specimen mounted in the larger 5-ton machine, but loaded by direct weights. The clamps in the lower, power-driven head were removed from the vertical driving and loading spindle. In place there was hung on the specimen a cast iron weight of about 450 lb. and a can into which lead shot was poured at a steady rate. Recording equipment was exactly as at first. Rate of loading in all three cases was comparable and normal — the entire test taking from three to five minutes.

In this test there was likewise no upper and lower yield point, but a steady increase of the load when passing the proportional limit (*K* to *L*). Furthermore the interesting and likewise foreseen fact is recorded that there is no drop whatever in the load up to the point of ultimate fracture. The last end of the curve, from *M* to *N*, continues on approximately the same level, but with a slight rise — only slight owing to the rapid development of a local necking while the stream of shot drops steadily into the bucket.

In our experiments (which were conducted by the faculty of metallurgy at Warsaw Polytechnic Institute) we also find that the recorded yield point of all soft steels and irons is too high. A revision of ideas will be necessary, as evidently the true yield range (*E* to *F*, or *K* to *L*) is considerably lower than the fictitious yield points ordinarily recorded in *A* and *B*. Some changes in ultimate strength are noted also, especially when making short time tests at high temperatures.

Furthermore it is evident that tensile testing machines designed for ductile materials require fundamental reconstruction so as to avoid a sudden drop in indicated load when the test piece rapidly elongates. G. WELTER

Notes on Trends in the Nitriding of Steel

TURIN, ITALY — Numerous new applications of nitriding have resulted from a better knowledge of the peculiar properties of new nitriding steels recently introduced in Europe other than the typical 1% aluminum steels originally adopted by Fry.

The nitriding steels may be subdivided into three classes: I. Chromium-molybdenum-aluminum steels containing about 1% aluminum. II. Lower alloys of the same nature, typically 0.35 to 0.45% C, 1.20 to 1.70% Cr, 0.25 to 0.35% Mo, 0.25 to 0.35% Al. III. Higher chromium-vanadium steels without aluminum. Of these the Class I steels are limited in use to very special cases and represent a small fraction of the tonnage. On the other hand, Class II and III steels are increasing in use very rapidly.

Wide experience with nitrided machine parts made of low aluminum steels has shown that their resistance to wear is practically the same as that obtained with steels of Class I, in spite of the fact that the superficial hardness is somewhat lower. The great advantage of a complete absence of brittleness in the nitrided layers in the low aluminum steels more than counterbalances the small difference in wear resistance.

This inherent toughness makes it possible to use nitrided steels satisfactorily for pieces with sharp-edged corners (such as parts of sewing machines or valves) and for pieces subject to impacts (such as pneumatic hammers, tools or cams). Another great practical advantage of these steels lies in the fact that the nitrided pieces are much less liable to that brittleness associated with low carbon, high aluminum steels. This therefore minimizes the risks of superficial exfoliation which is to be expected with the 1% aluminum steels when the slightest surface decarburization has taken place during heat treatment prior to the nitriding heat.

The nitriding steels principally used at the present time in Europe are those of Class II, containing about 0.3% aluminum, but there is a marked increase in the applications of steels of the third class, containing no aluminum. In the latter steels there is a marked tendency toward a substantial increase in the vanadium content, 0.5 to 0.8% being frequently used.

More complex nitriding steels with chromium contents running from 8 to 20% have also found interesting applications in spite of the fact that the time required to obtain a case of a given depth is much longer than with normal nitriding steels. (Some notes on this are contained on page 39 of METAL PROGRESS, last month — Editor). Many makers of airplane engines have definitely adopted these steels for valves. Nitriding is limited to the stems; a 60-hr. heat is usual.

Another type of valve wear has been so serious that its correction by the use of nitrided steels is worthy of description.

Serious troubles are apt to occur in the regulation of hydraulic turbines, owing to rapid wear of the two essential pieces in the water passages — the needle and the mouthpiece. This is true especially for very high heads and pressures, and when the water contains hard mineral particles in suspension acting as an abrasive, yet too fine or flocculent to be completely eliminated in settling basins or reservoirs.

In such cases, a proper choice of the metal may minimize the trouble, but it is often practically impossible to determine the wear resisting qualities of metals by laboratory experiments. It is well known that such laboratory determinations are always difficult, but the difficulty becomes a practical impossibility when the nature of the abrasive matter cannot be well defined, and when its action takes place under the direct influence of dynamic phenomena so complicated and changing as those prevailing in the nozzle of a hydraulic turbine.

Therefore, useful information can be gathered only when one can study directly the behavior of different metals in one or more turbines, working under constant conditions. This has been done in one Italian power station containing three Pelton wheels built by the Società Costruzioni Meccaniche Riva of Milan. The water fall is 3300 ft., the turbines rotate at 500 r.p.m. and each one generates 26,000 kilowatts.

The turbines gave excellent results except that the regulating needles and the mouthpieces — originally made of medium hard forged carbon steel — immediately showed rapid wear.

This wear was especially bad on the needles, and mostly localized in the two-thirds of their body toward the point. They usually had to be replaced with much trouble and delay after two months (1400 hr.) of service. But leaving aside the cost and trouble of replacement, it is necessary to take into account the more important fact that the shape of needle and mouthpiece is impaired long before they are actually taken out of service, thus interfering with the efficient working of the turbine.

Many materials were tried, but only nitrided steel gave completely satisfactory results. I report here the results in hours of regular service until replacement or repair would be required for some of the metals used:

Nickel bronze	1,000 hr.
Medium hard carbon steel	1,400
Cast manganese steel	1,700
Forged hard carbon steel	2,100
Forged hard tungsten steel	8,500
Nitrided steel	19,000

Besides the advantage of much longer service, the pieces made of nitrided steel cost much less than those of high tungsten steel, their nearest competitor. For the other materials above quoted, it is evident that the question of cost does not arise; for instance, the pieces of nitrided steel cost 100% more than forged hard carbon steel, but they last 860% longer!

FEDERICO GIOLITTI

Iron Oxide Printing

LEOBEN, AUSTRIA — Many suggestions have been made in the past about the proper way to make contact prints on smooth surfaces of iron and steel, thus showing the location of various segregates. Of these suggestions perhaps the method of "sulphur printing" is most widely practiced.

Another method has rather extensively been experimented with by us in the metallurgical department of the Leoben Technical Institute, which for lack of a better name may be called "iron oxide printing." It was, I believe, originated by M. Niessner of Vienna. Probably it will be new to most American metallurgists, and perhaps a few of them will try the method and communicate their findings to METAL PROGRESS.

Iron oxide printing will show the size and distribution of those non-metallic inclusions (irrespective of their mineralogical nature) which contain more than a certain percentage of iron. What this percentage is cannot now be stated with precision, and probably is different in silicates, sulphides, oxides, phosphides, and so on. The process follows:

Gelatine paper is moistened with a dilute aqueous solution of hydrochloric acid (5 cc. concentrated HCl to 100 cc. H_2O) for about 5 min. Then the paper is lightly pressed between pieces of filter paper. In no case should drops of liquid be allowed to remain. The next step is to press the plane surface of the specimen (which should be polished and without scratches) against the gelatinized side of the paper for about 5 sec. The specimen is then removed from the paper and the latter is put into a solution of potassium ferrocyanide (20 g. $K_4Fe(CN)_6$ to 1000 cc. H_2O), where the picture is developed. Solutions of potassium ferricyanide may also be used, but a lower concentration is to be recommended.

Such development gives a general slight blue on the whole area where the specimen and the paper had touched each other. In addition dark blue spots will be found at the places where iron-bearing non-metallic inclusions are present on the surface of the specimen, exactly according to their distribution and size.

The following points must be borne in mind:

A minimum iron content in the inclusions is necessary to give a contrasting spot. Artificial inclusions of pure alumina, silica and clean molding sand did not show up as did particles of iron ore or scale.

A little exaggeration of the size of the inclusions may occur on account of diffusion and capillarity effects in the gelatine, but in most cases this enlargement can hardly be measured. Choice of paper (which is best done by means of a few preparatory tests), slight changes in the developing conditions, or concentration of reagents will keep this matter in control.

Very small inclusions do not always give clear, dark blue points on the print. It may be hoped, however, that further experimental work with this printing method will also correct this deficiency.

The paper must be dry enough. Drops of the liquid acid solution entering the developing solution will form clouds of a blue color, which make the print dirty, foggy and useless.

Fresh developing solutions should be used, otherwise the same blue clouds may occur.

Cleanliness is an important factor. Instead of using the fingers, one should use tongs with platinum tips or of hard wood.

In my experience good prints will always result when the above precautions are taken.

ROLAND MITSCHE

Continuous Contraction of Hot Valve Steels

MOSCOW, U.S.S.R. — The phenomenon of irreversible increase in the dimensions of cast iron and some aluminum alloys (the so-called "growth" of alloys) was observed long ago and has been widely investigated. The opposite phenomenon — an irreversible contraction in steel — has, as far as the present writer knows, never been described in the literature. Hence the results of some experiments made in the Institute of Aircraft Materials under the general guidance of Prof. George W. Akimov will be interesting as showing this phenomenon. They also throw some light on the decomposition of austenite in high alloy steels.

In order to study the effect of various heat treatments on the warpage of valve steels, as well as to fix clearance limits for valve stems, these high alloy steels were heated and cooled in a Chevenard dilatometer, the changes in length with time and temperature being automatically recorded. The steel now to be described had the following analysis: Carbon 0.35%, chromium 13.3%, nickel 8.0%, silicon 2.8% and manganese 0.45%.

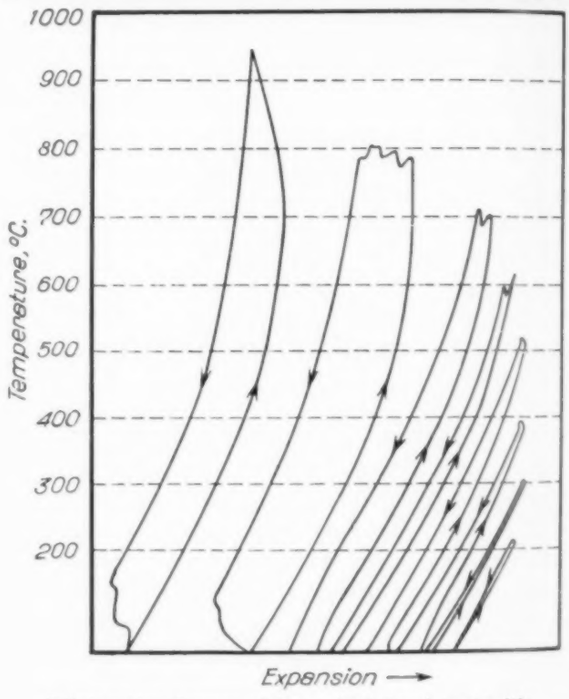
This steel after quenching from 1100° C. (2000° F.) had the usual coarse grained, single phase structure of austenite. When this quenched austenite steel is heated gradually a contraction occurs between 750 and 900° C. (1400 and 1650° F.); on cooling a reverse expansion occurred quite rapidly below 150° C. (300° F.). The dilatometer curve in question is shown at the left of the group herewith. When tested at room temperature this sample was considerably harder than before the reheating, and the microstructure was also changed; a darkly etching constituent had precipitated along the austenitic grain boundaries and twinning planes across the crystals of the metal.

Next a series of tests were made in the dilatometer by heating a quenched (austenitic) sample gradually to 200° C., 300° C., and so on by 100° steps up to 800° C., and retaining at the top temperature for several hours before slow cooling. The corresponding curves are shown. It will be observed that little or no change occurred in the dimensions of the austenite during soaking at any temperature below 700° C., but that a notable contraction — on the order of 0.0005 of the length — occurred during a long stay at 800° C. (1475° F.)

Jeffries and Archer in "The Science of Metals," page 427, write as follows on the subject:

"It is well known that the transformation of gamma to alpha iron takes place with increase in volume. Andrew, Rippon, Miller, and Wragg have shown that the formation of cementite from austenite causes a contraction. When the steel contains about 1.0% carbon this contraction is sufficient to counteract the expansion due to the allotropic transformation of the iron; a 1.0% carbon steel slowly cooled from the austenitic condition will, therefore, undergo no appreciable volume change other than that due to its normal temperature coefficient. When such a steel is quenched so as to form martensite, however, there is an increase in volume comparable to that accompanying the allotropic change. The expansion has been shown by Chapin to take place at a low temperature, below 300° C., and to occur simultaneously with the reappearance of magnetism and with the development of marked hardness . . . .

(Continued on page 72)



Dilatometer Curves of Quenched Semi-Austenitic Steel. Heating at or above 800° C. (1475° F.) causes carbides to precipitate and the sample to contract; austenite, however, is retained on subsequent cooling until 150° C. (300° F.)